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**MEASURED EFFECTS OF THE VARIOUS COMBINATIONS
OF NUCLEAR RADIATION, VACUUM, AND
CRYOTEMPERATURES ON ENGINEERING MATERIALS**

Quarterly Progress Report

9 November 1962 through 28 February 1963

E. J. ...
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Prepared by
George C. Marshall Space Flight Center
Huntsville, Alabama

Contract No. NAS8-2450 (Mod. 3)
Request No. TP-35130 (IF)

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E. E. KERLIN

E. T. SMITH

**Prepared for
George C. Marshall Space Flight Center
Huntsville, Alabama**

**Contract No. NAS8-2450 (Mod. 3)
Request No. TP3-85130 (IF)**

GENERAL DYNAMICS | FORT WORTH

This report was prepared by General Dynamics/Fort Worth under Contract No. NAS8-2450, Modification 3, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center, with Eugene C. McKannan acting as project manager.

SUMMARY

The first year of operation under NASA Contract NAS8-2450 was completed on 9 November 1962. The contractual requirements, carried out by the Nuclear Aerospace Research Facility (NARF) of General Dynamics/Fort Worth (GD/FW), involved the measurement of various engineering properties of spacecraft materials under the combined environments of nuclear radiation and high vacuum (10^{-6} torr), and nuclear radiation and cryotemperatures (-320°F and -423°F).

Representative measurements which were made include lap-shear strength, ultimate tensile strength, ultimate elongation, stress-strain characteristics, compression strength, weight loss, spectral reflectivity, hardness, and lubricity. Representative test-material categories included adhesives, seals, thermal insulations, electrical insulations, potting compounds, dielectric materials, structural laminates, thermal control coatings, and lubricants.

References 1 and 2 are the first annual reports of the work carried out under the contract between 9 November 1961 and 9 November 1962.

The second year's work will be a continuation of that carried out in the first year with an expansion in the number of materials tested, a greater variety of tests, and the addition of tests to be conducted in the triple environment of nuclear radiation, high vacuum, and cryotemperature.

Under the nuclear-radiation high-vacuum section of the contract, fifty materials from eight material categories will be tested. Most of these materials will be irradiated in vacuum for three doses and in air for the same doses, then tested in air. Fifteen of these materials will also be tested in vacuum immediately after irradiation in vacuum (without exposing the materials to ambient air).

To perform the tests in vacuum, GD/FW designed and built equipment in which test specimens could be irradiated in a vacuum environment and subsequently tested without breaking the vacuum.

Effort during this first quarter of 1963 consisted of modifying the tensile testers, writing a test plan for the year's program and selecting and ordering the test materials. A complete list of the test materials and the various irradiation environments is given in Section II of this report.

Under the radiation-cryotemperature section of this contract, sixteen materials under seven material categories will be tested. The categories are adhesives, seals, thermal insulation, electrical insulations, structural laminates, potting compounds, and sealants. Tests will be performed on materials during exposure to three different temperatures (ambient, -320°F , -423°F) and after exposure to zero, low, and high doses of nuclear radiation. Thus, nine data points will be obtained for each material for each type of test. Tests scheduled for materials under the different categories include tensile shear strength, ultimate tensile strength,

ultimate elongation, stress-strain characteristics, T-peel strength, potted-wire pull-out strength, leakage, and thermal conductivity.

To perform the tests at cryotemperatures, GD/FW designed and built three experimental assemblies in which test specimens could be submerged in liquid nitrogen or liquid hydrogen, during exposure to nuclear radiation, and subsequently tested in tension.

Effort during this first quarterly period of 1963 consisted of decontaminating, repairing, and modifying the assemblies; designing a thermal conductivity tester, selecting and ordering the materials to be tested; and writing a complete test plan for the year's work. A tabulation of the materials, tests to be performed, and specimen breakdown are shown in Tables 3.1 through 3.11.

A new program added this year calls for investigating the combined effects of radiation, vacuum, and cryogenic temperatures on selected materials. This work is to be an extension and combination of the work carried out under the two sections described above. The materials tests will be accomplished during or after irradiation with the materials still in the vacuum or after irradiation with the materials still in the vacuum and at cryotemperatures. Two types of measurements are to be made: one for electrical properties, consisting of dissipation factor and dielectric constant, and the other for mechanical properties consisting of ultimate tensile strength and elongation.

TABLE OF CONTENTS

	<u>Page</u>
REPORT SUMMARY	3
LIST OF FIGURES	9
LIST OF TABLES	11
I. INTRODUCTION	13
II. COMBINED EFFECTS OF RADIATION AND VACUUM	15
2.1 Material Section	16
2.1.1 Structural Adhesives	21
2.1.2 Structural Laminates	23
2.1.3 Potting Compounds	24
2.1.4 Electrical Insulation	25
2.1.5 Seals	26
2.1.6 Dielectric Materials	26
2.1.7 Thermal Insulations	28
2.1.8 Lubricants	29
2.2 Test Procedure	29
2.3 Nuclear-Dose Measurement Plan	44
2.4 Test Equipment	45
2.4.1 Vacuum-Irradiation Chamber	45
2.4.2 Experimental Test Apparatus	45
III. COMBINED EFFECTS OF RADIATION AND CRYOTEMPERATURE	49
3.1 Test-Material Selection	49
3.2 Test Plan	50
3.2.1 General	50
3.2.2 Test Equipment	64
3.2.3 Test Specimens	74
3.2.4 Irradiation Test	74
3.3 Nuclear Measurements Plan	81
3.3.1 Ambient Irradiation	81
3.3.2 LN ₂ Irradiation	83
3.3.3 LH ₂ Irradiation	83

TABLE OF CONTENTS (cont'd)

	<u>Page</u>
IV. COMBINED EFFECTS OF RADIATION, VACUUM, AND CRYO-TEMPERATURE	85
4.1 Test Plan	85
4.2 Nuclear-Radiation-Level Measurements for the Vacuum-Cryotemperature Irradiation System	86
4.2.1 Neutron Flux and Spectrum Monitoring	86
4.2.2 Gamma Dose Measurement	87
4.2.3 Summary	87
APPENDIX	89
REFERENCES	99
DISTRIBUTION	101

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
3.1	Various Views of Experimental Assembly	67
3.2	Thermal-Conductivity Tester	69
3.3	Bottom View of Thermal-Conductivity Tester	70
3.4	Mounting Assembly for Thermal-Conductivity Tester	73
3.5	Lap-Shear Specimen: Material A	75
3.6	Lap-Shear Specimen: Material B	76
3.7	Dumbbell-Type Specimen: Materials D, H, and I	77
3.8	Dumbbell-Type Specimen: Materials J, K, and L	78
3.9	Potted-Wire Tester: Materials M and N	79
3.10	T-Peel Tester (Type A and B): Materials O and P	80
3.11	Irradiation-Position Breakdown for Four Weeks of Irradiations Scheduled for Radiation-Cryotemperature and Radiation-Vacuum Tests	82
A-1	Basic Cylindrical Geometry	93
A-2	Cylindrical Geometry Using Three Concentric Cylinders of Different Materials	96

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Approved Materials and Test Specimen Configuration for Combined Vacuum and Irradiation Experiment	17-20
2.2 Effects of Air Irradiation at Two Temperatures on Precision Rubber Products Compound 737-70-FLX	27
2.3 Test Plan for Vacuum-Irradiation of Structural Adhesives	30-31
2.4 Test Plan for Vacuum-Irradiation of Structural Laminates	32-33
2.5 Test Plan for Vacuum-Irradiation of Potting Compounds	34-35
2.6 Test Plan for Vacuum-Irradiation of Electrical Insulations	36-37
2.7 Test Plan for Vacuum-Irradiation of Seals	38
2.8 Test Plan for Vacuum-Irradiation of Thermal Insulation	39
2.9 Test Plan for Vacuum-Irradiation of Dielectric Materials	40-41
2.10 Test Plan for Vacuum-Irradiation of Lubricants	42
3.1 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Adhesives	51
3.2 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Seals	52
3.3 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Thermal Insulations	53
3.4 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Electrical Insulations	54-55
3.5 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Structural Laminates	56
3.6 Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Potting Compounds	57

LIST OF TABLES (CONT'D)

<u>Table</u>		<u>Page</u>
3.7	Irradiation and Control Runs (Ambient, LN ₂ , LH ₂): Sealants	58
3.8	Test-Specimen Breakdown and Summation	59-60
3.9	Specimen and Rod Distribution: Two Assemblies (LN ₂ or LH ₂ Run)	61
3.10	Specimen-Mounting Apparatus Requirements: Two Assemblies (LN ₂ or LH ₂ Run)	62
3.11	Radiation Damage Levels	63

I. INTRODUCTION

Many of the component parts of nuclear-powered spacecraft will be exposed, during flight, to environments composed of the various combinations of nuclear radiation, high vacuum, and cryotemperatures. The first known tests to measure the engineering properties of spacecraft materials during exposure to the combinations of radiation and high vacuum and of radiation and cryotemperature were conducted by the Nuclear Aerospace Research Facility at General Dynamics/Fort Worth during 1962. Annual progress reports covering this work have been published (Refs. 1, 2). Effort during 1963 (designated as Modification 3 to the original contract) will be a continuation of that which was started last year and will include an additional phase of work designed to demonstrate the combined effects on materials of the triple environment of radiation, high vacuum, and cryotemperature.

Material categories covered in tests performed during the first year included adhesives, seals, thermal insulations, electrical insulations, structural laminates, thermal control coatings, potting compounds, and lubricants. Representative tests were those suitable for measuring lap-shear strength, ultimate tensile strength, ultimate elongation, stress-strain characteristics, weight loss, lubricity, compressive strength, and spectral reflectivity.

During the second year's work in 1963, essentially the same tests will be performed on a new group of materials selected from the same material categories. Additional tests will include the measurement of thermal conductivity, dissipation factor, dielectric strength, T-peel strength, and potted-wire pull-out strength.

Work during the first quarter of 1963 included decontamination, repair, and modification of the experimental equipment; selection and ordering of the test materials; design of apparatus to perform the added tests; and writing of a complete test plan for the entire operation during the year.

II. COMBINED EFFECTS OF RADIATION AND VACUUM

The irradiation of materials in a high vacuum changes two conditions present in an air irradiation. The first is the removal of oxygen and ozone; the second, the separate effect of the vacuum on the free radicals produced in the material during irradiation. The interaction of these conditions makes it impossible to predict property changes due to vacuum irradiation on the basis of changes due to air irradiation.

The results of the first year's effort on this continuing program to measure the combined effects of radiation and vacuum are present in the first annual report (Ref. 1). These results show that the presence of the vacuum environment during irradiation influence the resulting property changes of materials in different ways. At present, no trend is apparent that would allow one to draw general conclusions about the effects of vacuum on nonmetallic engineering materials during irradiation. The annual report accounted for (1) ten materials that showed no significant change in measured properties caused by vacuum-radiation of 1.0×10^{10} ergs/gm(C) or higher and 10^{-6} -torr pressure and (2) four materials that showed no changes in measured properties after doses of 1.0×10^9 ergs/gm(C) or higher during the vacuum irradiation. The remaining 33 materials changed, with a few materials decreasing 99% in measured properties after the vacuum irradiation.

The test program for this year will be a continuation of the program initiated last year to provide data on the effects of vacuum radiation on selected materials applicable for use

in nuclear-powered spacecraft. This program is designed to test a large number of materials to show the different effects produced by (1) air irradiation, (2) vacuum irradiation and testing in air, and (3) vacuum irradiation and testing in vacuum. Many of the materials tested in last year's program will be tested at higher or lower doses during this program.

2.1 Material Selection

The materials selected and tested in the first year of this program are still in current use in space vehicles. The continued testing of these materials is warranted to determine their effective useful life in the combined environments of radiation and vacuum. Twenty-three new materials have been added to the program to make a total of 50 materials to be tested. A complete list of the materials, together with the ASTM test procedures to be used in these tests, is given in Table 2.1. Data on the radiation and vacuum characteristics of those materials tested last year and again selected for this year's test are reported in References 3, 4, and 5. These data plus the data presented in the annual report (Ref. 1) are sufficient to justify their selection. The new materials selected for testing are identified by asterisks in Table 2.1 and are used in current missile programs; however, there is little radiation-effects information available on them.

Table 2.1

Approved Materials and Test Specimen Configuration
for Combined Vacuum and Irradiation Experiment

Category	Chemical Class	Trade Name	Manufacturer	ASTM Test Specimen Configuration
Structural adhesive	Epoxy	Shell 929	Shell Chemical Co.	Lap shear per ASTM D-1002-53T
	Epoxy	Shell 934	Shell Chemical Co.	Lap shear per ASTM D-1002-53T
	Epoxy-nylon	FM-1000	Bloomingtondale Rubber Co.	Lap shear per ASTM D-1002-53T
	Epoxy-phenolic	HT-424	Bloomingtondale Rubber Co.	Lap shear per ASTM D-1002-53T
	Epoxy-phenolic	Aerobond 430	Adhesive Engr. Co.	Lap shear per ASTM D-1002-53T
	Modified epoxy	Narmco A	Narmco Material Division	Lap shear per ASTM D-1002-53T
	Vinyl-phenolic	FM-47	Bloomingtondale Rubber Co.	Lap shear per ASTM D-1002-53T
	Nitrile-phenolic	Metlbond 4021	Narmco Material Division	Lap shear per ASTM D-1002-53T
	Polyurethane	APCO 1252	Applied Plastics Co.	Lap shear per ASTM D-1002-53T
	Polyurethane	Narmco C	Narmco Material Division	Lap shear per ASTM D-1002-53T
Structural laminate	Phenolic	Mobilloy AH-81	Cordco Moulding Products	Modified Type II tensile specimen per ASTM D-638-58T
	Polyester glass fabric	Paraplex P-43	Rohm and Haas	Modified Type II tensile specimen per ASTM D-638-58T
	Silicone-glass fabric	DC 2104	Dow Corning Corp.	Modified Type II tensile specimen per ASTM D-638-58T
	Polyester-glass fabric	Selectron 5003	Pittsburgh Plate Glass	Modified Type II tensile specimen per ASTM D-638-58T
	Phenolic-fiber-glass	HRP Honeycomb	Applied Plastics Co.	Compression

Table 2.1 (cont'd)

Category	Chemical Class	Trade Name	Manufacturer	ASTM Test Specimen Configuration
Potting compounds	Silicone elastomer	RTV-60	General Electric	(1) Compression specimen per ASTM D-575-46 (2) Wire pull test specimen
	Silicone elastomer	RTV-501	Dow Corning Corp.	(1) Compression specimen per ASTM D-575-46 (2) Wire pull test specimen
	Ceramic	Durock D-133	Physical Science Corp.	Compression specimen per ASTM D-695-54
	Silicone resin	DC R-7521	Dow Corning Corp.	Wire pull test specimen
	Epoxy resin	Scotchcast 212	Minnesota Mining & Manufacturing Co.	(1) Compression specimen per ASTM D-695-54 (2) Wire pull test specimen
Electrical insulation	Vendor proprietary	EC-2273	Minnesota Mining & Manufacturing Co.	(1) Compression specimen per ASTM D-575-46 (2) Wire pull test specimen
	Silicone elastomer	DC 7-170	Dow Corning Corp.	Tensile specimen per ASTM D-412-51T (Die C)
	Fluoroethylene	KEL-F-81	Minnesota Mining & Manufacturing Co.	(1) Modified Type II tensile specimen per ASTM D-638-58T (2) Flexure specimen per ASTM D-790-58T
	Polyester	Mylar A	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Polyethylene	Marlex 6002	Phillips Chemical Co.	Tensile specimen per ASTM D-882-56T
Dielectric Materials	Fluoroethylene	Teflon TFE (10 mil)	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Fluoroethylene	Teflon TFE (40 mil)	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-638-58T

Table 2.1 (cont'd)

Category	Chemical Class	Trade Name	Manufacturer	ASTM Test Specimen Configuration
Dielectric materials (cont'd)	Fluoroethylene	Teflon FEP (10 mil)	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Fluoroethylene	Teflon FEP (40 mil)	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-638-58T
	Polyvinyl	Tedlar	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Polyamid	H-Film	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Polyamid	SP Plastic	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Polyolofin	Thermofit (Royolin R)	Raytherm Corp.	Tensile specimen per ASTM D-412-51T (Die C)
Thermal insulation	Polyurethane	CPR 20	Chemical Plastic Research	Compression specimens per ASTM D-1565-58T
	Polyurethane	CPR 1021-2	Chemical Plastic Research	Compression specimens per ASTM D-1565-58T
	Polyester	Mylar C	E. I. du Pont de Nemours Co.	Tensile specimen per ASTM D-882-56T
	Polyvinyl chloride	Geon 2046	B. F. Goodrich Chemical Co.	Tensile specimen per ASTM D-412-51T (Die C)
	Polyvinyl chloride	Geon 8800	B. F. Goodrich Chemical Co.	Tensile specimen per ASTM D-412-51T (Die C)
	Polyvinyl chloride	Estane 5740X1	B. F. Goodrich Chemical Co.	Tensile specimen per ASTM D-412-51T (Die C)
	Fiberglass, reinforced	Duroid 5600	Rogers Corp.	Modified Type II tensile specimen per ASTM D-638-58T
	fluoroethylene			

Table 2.1 (cont'd)

Category	Chemical Class	Trade Name	Manufacturer	ASTM Test Specimen Configuration
Thermal Insulation (cont'd) Seals	Fiberglass, modified fluoroethylene	Kyner	Pennsalt Chemical Co.	Tensile specimen per ASTM D-412-51T (Die C)
	Natural rubber	RA-33860	Marshall Space Flight Center	O-rings per ASTM D-1414-56T
	Viton B	PRP 19007	Precision Rubber Products	O-rings per ASTM D-1414-56T
	Acrylo-nitrile	PRP 737-70-FLX	Precision Rubber Products	O-rings per ASTM D-1414-56T
	Neoprene	PRP 2277	Precision Rubber Products	O-rings per ASTM D-1414-56T
	Buna N	66-581	Parker Seal Co.	O-rings per ASTM D-1414-56T
Lubricants	Silicone	GE F-50	General Electric	Bearing lubricant
	Silicone	ETR-H	Shell Oil Co.	Bearing lubricant
	MoS ₂ + epoxy binder	Electro-film 66-C	Electro Film, Inc.	Bearing lubricant
	MoS ₂ + sodium binder	MLF-5	Midwest Research Institute	Bearing lubricant
	Teflon + fiberglass	Duroid type	Rogers Corp.	Bearing lubricant

2.1.1 Structural Adhesives

Eight adhesive formulations representative of the six major types of adhesive systems were tested during the previous program. Three of the formulations that showed significant changes in mechanical properties after the vacuum-irradiation were Metlbond 408 (an epoxy-nylon) Epon VIII (an epoxy), and FM-47 (a vinyl phenolic). The FM-47 showed a higher change in properties than has been predicted, and will be retested this year to verify these results. The FM-1000 tested last year will be tested at a higher dose this year.

Eight new formulations to be added this year include one material from each of the major adhesive systems. The materials will be irradiated in both air and vacuum.

Shell Chemical Company reports (Ref. 6) data for Epon 929 and 934 selected for testing. These materials were irradiated for a dose of 1×10^{11} ergs/gm(C) at 100°C in a gamma source and tested at room temperature. Epon 929 with a control tensile-shear strength of 2605 psi increased 6% after the irradiation exposure. Epon 934 increased from a control value of 3050 psi to 3130 psi, a gain of 3%. After a dose of 3×10^{11} ergs/gm(C) at 95°C , Epon 929 and 934 increased 10% and 8%, respectively.

Aerobond 430 and HT 424 were selected for testing from the epoxy-phenolic group. The epoxy phenolics as a class have excellent high-temperature stability and are serviceable at cryogenic temperatures. No radiation or vacuum data were found for these materials; however, they have been successfully used in the Saturn S-1 space vehicle.

Based on the performance of other epoxies, Narmco A, a modified epoxy, should have good resistance to both radiation and vacuum.

Metlbond 4021 was selected for testing from the nitrile-phenolic group during last year's evaluation, but the samples arrived too late to be included in the test program. The data presented in Reference 7 show that ambient tensile-shear strength of 4,200 psi was unchanged after 5×10^{10} ergs/gm(C) dose. Metlbond 4021 has a tensile-shear strength of 1800 psi at -320°F (Ref. 8).

The only radiation data available on polyurethane adhesives were generated last year in the cryogenic portion of these experiments (Ref. 2). The data show that APCO 1252 (formerly called Hexcel 1252) had tensile-shear values of 2240 psi, 4212 psi, and 5028 psi respectively for the controls, reactor radiation in air at ambient temperatures for 1.0×10^{10} , and 6.0×10^{10} ergs/gm(C). The material had the following tensile-shear values when tested in liquid nitrogen: 5040 psi, 4592 psi, and 4248 psi, respectively, for controls, specimens irradiated in liquid nitrogen of 1.39×10^{10} ergs/gm(C), and specimens irradiated in liquid nitrogen of 6.3×10^{10} ergs/gm(C). When tested in liquid hydrogen, the material had the values of 5228 psi for the controls and 4536 psi after the reactor irradiation of 2.0×10^{10} ergs/gm(C). These values show that this material retained good physical properties after the air and cryogenic irradiations, and for reasons of completeness and reproducibility of the data APCO 1252 will be tested in air and vacuum. Narmco C, a polyurethane material, should have radiation resistance similar to APCO 1252.

2.1.2 Structural Laminates

Five structural laminates, tested during the previous program, were representative of three of the four major chemical classes of laminate materials. The samples for the fourth material class (Paraplex P-43) arrived too late to be included in that program. These will be irradiated this year.

Mobiloy 81-AH7 was tested during the previous program as a single sheet of laminate glass cloth impregnated with the resin. This year it is being obtained as a standard laminate, 1/8 inch thick, to be retested as a standard specimen.

Of the silicone laminates, DC 2104 has been selected for testing. The available data for this material (Ref. 9) show no change in physical properties after 9.5×10^{10} ergs/gm(C) irradiation. DC 2106, also a silicone material, showed no change in properties (Ref. 1) when irradiated in 5×10^{-7} -torr vacuum for a dose of 4.5×10^{10} ergs/gm(C).

Selectron 5003 and Paraplex P-43 were reselected from the polyester group to be tested this year. Selectron 5003 has been tested (Refs. 10, 11, 12, 13) to doses as high as 2.5×10^{11} ergs/gm(C) and shows no change in physical properties. During last year's program this material was selected as an alternate to Paraplex P-43.

The late arrival of the Paraplex P-43 samples prevented their inclusion in the irradiations. Air irradiation of this material (Ref. 13) showed no changes in physical properties after doses of 10^{11} ergs/gm(C). The material also showed no damage from a 500-hour room temperature exposure in 10^{-6} -torr vacuum. However, when exposed

for 24 hours to a vacuum of 10^{-6} torr while at a temperature of 300°F, the laminate showed a loss of 2% in weight and 20% in tensile strength.

The HRP Honeycomb is a phenolic-fiberglass composition. The phenolics as a group have shown no change in physical properties when they were irradiated to doses in the order of 1×10^{10} ergs/gm(C).

2.1.3 Potting Compounds

Three potting compounds were tested in the program last year. The fourth material, Durock D-133, which arrived too late to be included in the first year's program, will be tested during this year. The epoxy formulation DC-R-7521 showed no significant change in strength as a result of vacuum irradiation, while the silicone elastomer RTV-60 showed a large increase in compression strength. RTV-60 will be retested to establish the doses required for smaller changes in physical properties. RTV-501 is a silicone elastomer with proven vacuum resistance (Ref. 14) and has shown no change in physical properties to radiation doses of 3×10^9 ergs/gm(C).

Scotchcast 212 is a semirigid epoxy potting formulation that has good resistance to radiation and vacuum (Ref. 15). The effects of 1.6×10^9 ergs/gm(C) is a slight gain in weight, about 20% increase in hardness, and a decrease in dissipation factor. In general, the physical properties were degraded slightly, and the electrical properties were improved significantly. No significant change at 10^{-6} -torr vacuum at 23°C for 20 hours was noted.

EC 2273 is a new potting and sealing formulation used successfully in missile (Saturn S-1) applications. The vendor has not

released the chemical type for formulation of this material. No radiation-effects data was found listed by this compound designation.

2.1.4 Electrical Insulation

Six materials were tested in this category during the program last year. Four of the materials will be retested in this program at lower or higher doses. Geon 2046, selected in last year's program but not tested because of limited space in the vacuum systems, will be tested this year. Justification for the selection of this material is given in Reference 4. Geon 8800 is a vinyl formulation for use at higher temperatures than Geon 2046. No vacuum or radiation data are available on this material, but it has been used successfully in the Saturn S-1 missile.

Estane 57040X1 is a poly (ester-urethane) elastomer which is believed to be an essentially linear polymer and which behaves as a typical thermoplastic. This material is being used as wire and cable jacketing and as fuel hoses in current missiles. No vacuum or radiation data were found for this material. However, based on data from the general chemical class, the material should be resistant to the combined environment of radiation and vacuum.

Duroid 5600 is a fiberglass-reinforced Teflon with proven serviceability as a bearing retainer in vacuum tests conducted by NASA. Data (Ref. 16) from air irradiation of a fiberglass-reinforced Teflon having another brand name showed the following properties: 25,303 psi, 20,264 psi, and 10,767 psi, respectively, for controls, air irradiation of 2.5(8) ergs/gm(C), and air irradiation of 1.2×10^{10} ergs/gm(C).

The material should have the same vacuum compatibility as standard Teflon.

Kynar is a modified Teflon that is being used in many applications in the Centaur vehicle. It is a heat-sealable material, but does not have as good low-temperature properties as Teflon. This material has exhibited excellent resistance to ultraviolet radiation.

2.1.5 Seals

Three types of O-ring formulations were tested during the program last year. All of the compounds showed large changes in physical properties after exposure to the combined environments. These materials along with two new materials will be tested at lower doses this year.

Precision Rubber Products Compound 737-70-FLX is based on Acrylonitrile-Butadiene rubber with three parts of FLX antioxidant as an antirad. The air irradiation results (Ref. 17) presented in Table 2.2 demonstrate the radiation stability of this compound. The vacuum stability will be determined by NASA.

Results of air irradiation tests of Precision Rubber Compound 2277 are given in Reference 4. These data are considered sufficient for these preliminary surveys and will not be repeated.

2.1.6 Dielectric Materials

Four types of dielectric materials were tested during the program last year. All of these materials showed large changes in mechanical properties after subjection to the combined environments. These materials will be retested this year at lower doses.

Table 2.2

Effects of Air Irradiation at Two Temperatures
on Precision Rubber Products Compound 737-70-FLX

Radiation Exposure		Temperature and Time (°F/hr)	Ultimate Tensile Strength (psi)	Ultimate Elongation (%)
Gamma [ergs/gm(C)]	Neutrons (n/cm ²) (E 2.9 Mev)			
0	0	75/	1884/145/3*	219/20/3
1.3 x 10 ⁹	2.17 x 10 ¹⁴	75/	2102/100/3	208/8/3
9.8 x 10 ⁹	1.6 x 10 ¹⁵	75/	2468/142/5	112/17/5
0	0	275/5	1974/252/3	184/18/3
1.3 x 10 ⁹	2.17 x 10 ¹⁴	275/5	2010/100/2	170/7/2
7 x 10 ⁹	9.3 x 10 ¹⁴	275/5	2158/213/5	105/12/5

*Avg value/standard deviation on an individual basis/no. of samples

The new material added to the test this year, Rayoline N, is an irradiated insulated wire polyolofin. This wire exhibits good flexibility and dielectric strength after 5×10^9 ergs/gm(C). The vendor reports (Ref. 18) that this material has passed a postirradiation test which consisted of (1) winding a section of the wire ten full turns over a mandrel having a diameter ten times the overall diameter of the insulated wire and (2) immersing the coil in an electrical conducting solution and applying a potential of more than 2200 volts to ensure the dielectric strength of the insulation. The vendor indicates that the material should have better vacuum compatibility than polyethylene.

2.1.7 Thermal Insulations

Five types of thermal insulation materials covering the major chemical classes were tested during the program last year. These materials showed small changes in compression strength (Ref. 1) after subjection to the combined environments; consequently, none of the materials will be retested this year.

Two new materials selected for testing this year have provided satisfactory service in the Saturn S-1 vehicle. These materials are a foam-in-place polyurethane. Radiation-effects information on these materials is not available at this time; however, based on the results of the two polyurethanes tested during last year's program, these materials should show small changes in properties after a vacuum-irradiation exposure of 5×10^9 ergs/gm(C).

2.1.8 Lubricants

None of the four lubricants tested last year shows good resistance to the combined environment of radiation, vacuum, and high temperature. Three of these materials will be retested this year at lower temperatures. The two new materials added to the program have shown good resistance to high-vacuum environments in tests performed by NASA. Both materials should possess relatively high radiation stability in the vacuum environment.

2.2 Test Procedure

Samples from the same batch of materials will be subjected to the following test conditions in this program: (1) qualification in vacuum, (2) irradiation in air, (3) irradiation in vacuum and testing in air, and (4) irradiation in vacuum and testing in vacuum.

The test materials will be qualified in vacuum at the anticipated irradiation temperatures by the use of the continuous-weight-loss technique. This work will be done at NASA at the George C. Marshall Space Flight Center in the vacuum laboratory. A description of their techniques and procedures is given in Reference 19. Later this year, NASA will initiate a program to determine the effects of vacuum and temperature on the mechanical properties of the same batch of materials tested in the combined environments.

Tables 2.3 through 2.10 presents the test plan for the air and vacuum irradiation. Thirty-five of the fifty test materials will be irradiated statically in vacuum and air and tested in air at the

Table 2.3

Test Plan for Vacuum-Irradiation of Structural Adhesives

Material	Irradiation Plan		Radiation Exposure [args/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Testor				
FM-1000	Vacuum	Instron	5(10) ¹	7	USS ²	July 22
	Air	Instron	1(10), 5(10)	7	USS	July 22
Shell 929	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Shell 934	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Apo 1252	Vacuum	High force	1(10)	5	USS	April 8
	Vacuum	High force	5(10)	5	USS	July 22
	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Metlbond 4021	Vacuum	High force	1(10)	5	USS	April 8
	Vacuum	High force	5(10)	5	USS	July 22
	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22

Table 2.3 (cont'd)

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Testor				
FM-47	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
HT-424	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Narmco A	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Narmco C	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
Aerobond 430	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22
	Vacuum	Instron	5(9)	7	USS	April 8
	Vacuum	Instron	1(10), 5(10)	7	USS	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	7	USS	July 22

¹5(10) read as 5 x 10¹⁰²Ultimate shear strength

Table 2.4

Test Plan for Vacuum-Irradiation of Structural Laminates

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Testor				
Mobilov 61-4H7	Vacuum	High Force	1(10)	4	UT ¹ , UE ² , SS ³	April 8
	Vacuum	High force	5(10)	4	UT, UE, SS	July 22
	Vacuum	Instron	5(9)	5	UT, UE, WC ⁴	April 8
	Vacuum	Instron	1(10)	5	UT, UE, WC	April 8
	Vacuum	Instron	5(10)	5	UT, UE, WC	July 22
	Air	Instron	5(9), 1(10), 5(10)	5	UT, UE	July 22
DC 2104	Vacuum	High force	1(10)	4	UT, UE, SS	April 8
	Vacuum	High force	5(10)	4	UT, UE, SS	July 22
	Vacuum	Instron	5(9)	5	UT, UE, WC	April 8
	Vacuum	Instron	1(10)	5	UT, UE, WC	April 8
	Vacuum	Instron	5(10)	5	UT, UE, WC	July 22
	Air	Instron	5(9), 1(10), 5(10)	5	UT, UE	July 22
Selectron 5003	Vacuum	Instron	5(9)	5	UT, UE, WC	April 8
	Vacuum	Instron	1(10), 5(10)	5	UT, UE, WC	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	5	UT, UE	July 22
Paraplex P-43	Vacuum	Instron	5(9)	4	UT, UE, WC	April 8
	Vacuum	Instron	1(10), 5(10)	4	UT, UE, WC	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	4	UT, UE	July 22

Table 2.4 (cont'd)

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
HRP Honeycomb	Vacuum	Instron	5(9)	5	UT, UE, WC	April 8
	Vacuum	Instron	1(10), 5(10)	5	UT, UE, WC	June 3 & July 22
	Air	Instron	5(9), 1(10), 5(10)	5	UT, UE	July 22

1Ultimate Tensile Strength
 2Ultimate Elongation
 3Stress Strain Curve
 4Weight Change

Table 2.5
Test Plan for Vacuum-Irradiation of Potting Compounds

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
RTV-60	Vacuum	Instron	1(8), 5(8), 1(9)	4	LD ¹	April 8
	Vacuum	Instron	5(8), 1(9)	1	WPT ²	April 8
	Air	Instron	1(8), 1(9)	5	LD	April 8
	Air	Instron	1(9)	1	WPT	April 8
RTV-501	Vacuum	Instron	1(8), 5(8), 1(9)	4	LD	April 8
	Vacuum	Instron	5(8), 1(9)	1	WPT	April 8
	Air	Instron	1(8), 1(9)	5	LD	April 8
	Air	Instron	1(9)	1	WPT	April 8
Durock D-133	Vacuum	Instron	5(10)	3	LD	July 22
	Air	Instron	5(10)	3	LD	July 22
DC R-7521	Vacuum	Instron	1(10)	1	WPT	July 22
	Air	Instron	1(10)	1	WPT	July 22
Scotchcast 212	Vacuum	Instron	5(8), 1(9), 5(9)	4	LD	April 8
	Vacuum	Instron	1(9), 5(9)	1	WPT	April 8
	Air	Instron	5(8), 1(9)	5	LD	April 8
	Air	Instron	5(9)	5	LD	July 22
	Air	Instron	5(9)	1	WPT	July 22

Table 2.5 (cont'd)

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
EC-2273	Vacuum	Instron	1(8), 1(9), 5(9)	4	LD	April 8
	Vacuum	Instron	1(9)	1	WPT	April 8
	Air	Instron	1(8), 1(9)	4	LD	April 8
	Air	Instron	5(9)	4	LD	July 22
	Air	Instron	1(9)	1	WPT	April 8

1Load Deflection
2Wire Pull Test

Table 2.6

Test Plan for Vacuum-Irradiation of Electrical Insulation

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
DC 7-170	Vacuum	Instron	1(8), 5(8), 1(9)	5	M ¹ , UT ² , UE ³ , WC ⁴	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8
KEL-F-81	Vacuum	Low force	5(7)	2	Flexure	July 22
	Vacuum	Low force	1(8)	2	Flexure	April 8
	Vacuum	Instron	5(7)	2	Flexure	July 22
	Vacuum	Instron	1(8)	2	Flexure	April 8
	Vacuum	Instron	5(7)	5	M, UT, UE, WC	July 22
	Vacuum	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
	Air	Instron	5(7), 1(8)	2	Flexure	April 8
	Air	Instron	5(7), 1(8), 5(8)	5	M, UT, UE, WC	April 8
	Vacuum	Instron	5(8), 5(9), 1(10)	5	M, UT, UE, WC	April 8
Mylar A	Air	Instron	5(8)	5	M, UT, UE	April 8
	Air	Instron	1(10)		M, UT, UE	July 22
	Vacuum	Instron	5(8), 1(9), 5(9)	5	M, UT, UE, WC	April 8
Mylar C	Air	Instron	5(8), 5(9)	5	M, UT, UE	April 8
	Vacuum	Instron	5(8)	5	M, UT, UE, WC	April 8
Geon 2046	Vacuum	Instron	1(10)	5	M, UT, UE, WC	June 3 & July 22
	Air	Instron	5(8)	5	M, UT, UE	April 8
	Air	Instron	5(9), 1(10)	5	M, UT, UE	July 22

Table 2.6 (cont'd)

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
Estane 5740X1	Vacuum	Instron	1(9)	5	M, UT, UE, WC	April 8
	Vacuum	Instron	1(10), 5(10)	5	M, UT, UE, WC	June 3 & July 22
	Air	Instron	1(9)	5	M, UT, UE	April 8
			1(10), 5(10)	5	M, UT, UE	July 22
Geon 8800	Vacuum	Instron	5(8), 1(9)	5	M, UT, UE, WC	April 8
	Vacuum	Instron	1(10)	5	M, UT, UE, WC	June 3 & July 22
	Air	Instron	5(8)	5	M, UT, UE	April 8
	Air	Instron	5(9), 1(10)	5	M, UT, UE	July 22
Duroid 5600	Air	Instron	1(8), 5(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 5(8), 1(9)	5	M, UT, UE	April 8
Kynar	Vacuum	Instron	5(7), 1(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	5(7), 1(8)	5	M, UT, UE, WC	April 8

¹Modulus
²Ultimate tensile
³Ultimate Elongation
⁴Weight Change

Table 2.7

Test Plan for Vacuum-Irradiation of Seals

Material	Irradiation Plan Environment	Tester	Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
RA-33860	Vacuum	Instron	5(8), 1(9), 5(9)	5	M ¹ , UT ² , UE ³ , WC ⁴	April 8
	Air	Instron	5(8), 5(9)	5	M, UT, UE	April 8
PRP-19007	Vacuum	Low force	5(7)	2	M, UT, UE	July 22
	Vacuum	Low force	1(8)	2	M, UT, UE	April 8
	Vacuum	Instron	1(8), 5(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8
PRP-737- 70-FLX	Vacuum	Instron	1(8), 5(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 5(8), 1(9)	5	M, UT, UE	April 8
PRP-2277	Vacuum	Instron	1(8), 5(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8
66-581	Vacuum	Low force	5(7)	3	M, UT, UE	July 22
	Vacuum	Low force	1(8)	3	M, UT, UE	April 8
	Vacuum	Instron	5(7), 1(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8

¹Modulus
²Ultimate Tensile
³Ultimate Elongation
⁴Weight Change

Table 2.8

Test Plan for Vacuum-Irradiation of Thermal Insulation

Material	Irradiation Plan		Radiation Exposure ergs/gm(C)	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
CPR 20	Vacuum	Low force	5(7)	3	Load-Deflection	July 22
	Vacuum	Low force	1(8)	3	Load-Deflection	April 8
	Vacuum	Instron	5(7)	5	Load-Deflection	July 22
	Vacuum	Instron	1(8), 1(9)	5	Load-Deflection	April 8
	Air	Instron	5(7), 1(8), 1(9)	5	Load-Deflection	April 8
CPR 1021-2	Vacuum	Low force	5(7)	3	Load-Deflection	July 22
	Vacuum	Low force	1(8)	3	Load-Deflection	April 8
	Vacuum	Instron	5(7)	5	Load-Deflection	July 22
	Vacuum	Instron	1(8), 1(9)	5	Load-Deflection	April 8
	Air	Instron	5(7), 1(8), 1(9)	5	Load-Deflection	April 8

Table 2.9

Test Plan for Vacuum-Irradiation of Dielectric Materials

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
Marlex 6002	Vacuum	Instron	1(8), 5(8), 1(9)	5	M 1, UT ² , UE ³ , WC ⁴	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8
Teflon TFE (10 mil)	Vacuum	Low force	5(7)	3	M, UT, UE	July 22
	Vacuum	Low force	1(8)	3	M, UT, UE	April 8
	Vacuum	Instron	5(7)	5	M, UT, UE, WC	July 22
	Vacuum	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
	Air	Instron	5(7), 1(8), 5(8)	5	M, UT, UE	April 8
Teflon TFE (40 mil)	Vacuum	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
Teflon FEP (10 mil)	Vacuum	Instron	5(7)	5	M, UT, UE, WC	July 22
	Vacuum	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
	Air	Instron	5(7), 5(8)	5	M, UT, UE	April 8
Teflon FEP (40 mil)	Vacuum	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 5(8)	5	M, UT, UE, WC	April 8
Tedlar	Vacuum	Instron	1(8), 5(8), 1(9)	5	M, UT, UE, WC	April 8
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8

Table 2.9 (cont'd)

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
Rayolene R	Vacuum	Instron	1(8), 1(9)	5	M, UT, UE, WC	April 8
	Vacuum	Instron	1(10)	5	M, UT, UE, WC	June 3
	Air	Instron	1(8), 1(9)	5	M, UT, UE	April 8
	Air	Instron	1(10)	5	M, UT, UE	July 22
H-Film	Vacuum	Instron	1(10), 5(10)	5	M, UT, UE, WC	June 3 & July 22
	Air	Instron	5(9), 5(10)	5	M, UT, UE	July 22

1 Modulus
 2 Ultimate Tensile
 3 Ultimate Elongation
 4 Weight Change

Table 2.10
Test Plan for Vacuum-Irradiation of Lubricants

Material	Irradiation Plan		Radiation Exposure [ergs/gm(C)]	No. Samples Per Test	Resulting Test Data	Scheduled Irradiation Date
	Environment	Tester				
GE-P-50	Vacuum	Bearing	0	2 motors	Lubricity	July
	Vacuum	Bearing	1(10)	2 motors	Lubricity	July 22
Shell ETR-H	Vacuum	Bearing	0	2 motors	Lubricity	July
	Vacuum	Bearing	1(10)	2 motors	Lubricity	July 22
Electro- film 66-C	Vacuum	Bearing	0	2 motors	Lubricity	July
	Vacuum	Bearing	1(10)	2 motors	Lubricity	July 22
Duroid (type)	Vacuum	Bearing	0	2 motors	Lubricity	July
	Vacuum	Bearing	1(10)	2 motors	Lubricity	July 22
MIL-P-5	Vacuum	Bearing	0	2 motors	Lubricity	July
	Vacuum	Bearing	1(10)	2 motors	Lubricity	July 22

Irradiated Materials Laboratory by the Instron tensile tester. The other materials will be irradiated in vacuum and tested by the dynamic testers while still in the vacuum. The High-Force Dynamic Tester, Low-Force Dynamic Tester, and the Bearing Lubricity Tester developed last year will be used in these tests.

Thirty-eight of these materials will be subjected to three radiation exposures. The lubricants will be subjected to one exposure and monitored continuously during this time. The remaining materials will be subjected to one or two exposures to pick up data points to complete the data history of these materials.

The three radiation doses are so picked that the damage induced in the material will be between the threshold of damage and the critical property threshold. The threshold of damage is defined as the integrated radiation dose at which pertinent property changes become apparent, and the critical property threshold is the integrated radiation dose at which a pertinent property changes to a low percentage of its initial value. Seven irradiation exposures ranging in value from 5×10^7 ergs/gm(C) to 5×10^{10} ergs/gm(C) will be used.

The ASTM test procedures used in the previous test program and reported in detail in Reference 4 will be used in these tests. These will be the test procedures generally used in evaluating the particular material.

The wire-pull test used in evaluating the adhesive efficiency of the potting compounds is being added to the program this year. (A drawing showing the test molds and potted-wire configuration is

shown in Figure 3.9.) The force required to pull the wires out of the potting compound will be measured after the vacuum irradiation.

The test plan for the Bearing Lubricant Test will be similar to that employed last year. The lubricants will be irradiated in vacuum of 10^{-6} torr to a dose of about 10^{10} ergs/gm(C) gammas over a period of 40 hours. Check-out of the test equipment will be made with the two extra motors. Preliminary measurements to characterize the ten lubricant-containing motors will be made prior to irradiation. At approximately one-hour intervals during vacuum-irradiation, measurements of coast-down time (by Eput meter), bearing temperature, current draw, vacuum pressure, no-load speed, and speed during coast-down will be made. The motors will be run continuously during vacuum-irradiation, except during data cycles. Postirradiation measurements will be made with the motors in vacuum for a total running time of 200 hours or until failure, whichever occurs first.

2.3 Nuclear-Dose Measurement Plan

The nuclear measurement techniques described in detail in the third quarterly progress report and used during the previous year's experiments will be used this year. These techniques called for the use of copper, sulphur, magnesium, and aluminum-foil disks placed at strategic locations during testing to measure the neutron fluxes at the following nominal energies: thermal, $E > 2.9$ Mev, $E > 7.5$ Mev, and $E > 8.1$ Mev, respectively. In order to monitor the gamma-ray dose inside the vacuum chamber, both nitrous-oxide (N_2O) and tetrachloroethylene (TCE) dosimeters will be used in these applicable energy response regions.

2.4 Test Equipment

2.4.1 Vacuum-Irradiation Chamber

The vacuum-irradiation chambers used during the program last year will be used this year. A detailed description of the systems, vacuum capabilities, and nuclear spectrum measurements is given in the annual report (Ref. 1). Replacement of the organic seals and the organic-insulated wires has been accomplished to ensure proper operation of the systems.

The electrical equipment on one vacuum that would be unsafe for use in hydrogen test areas is being replaced with approved equipment or removed to a safe area. This equipment is secondary to the chamber and should not affect the vacuum pumping capabilities.

2.4.2 Experimental Test Apparatus

2.4.2.1 Low- and High-Force Testers

Small modification to the travel and position indicators have been made to the dynamic testers to ensure proper operation. The Linear Variable Differential Transformer (LVDT) travel indicator was attached in a more rigid manner to the structure, and the moveable core has been extended $1\frac{1}{2}$ inches. These two modifications should prevent the jamming problem that was encountered during the last test.

An additional pull-rod-travel indicator has been added to the low-force tester. This indicator uses a 3-turn potentiometer operated by a rack and pinion setup. This system provides an extension measurement accuracy of approximately 0.01 inch over the full four inches of travel. The potentiometer travel will be used mainly

for the long pulls of O-rings and film and as a check of the LVDT travel indication for the compression pull positions.

The position-indicator-switch gear was positively secured by bolting the gear hub to the main shaft.

2.4.2.2 Lubricant Tester

Kearfott R-112 servo motors have been selected for use in the bearing-lubricant test. These size-18 servo motors are 1.750 inches in diameter and 2-1/32 inches long. The no-load speed is 9800 rpm, the stall torque 2.8 oz-in., and the weight 12.2 oz. The motors operate on 400 cps, 115 volts per phase, 2-phase power with a current draw of 226 ma per phase, and power input of 15.8 watts. The operating temperature range of the motors is -54°C to +2.04°C. The motors are continuous duty. The rotor moment of inertia is 4.0 gm-cm² and coast-down times of from 1 to 5 seconds have been measured for this type of motor.

The standard R-112 motor has R3-size bearings (0.1875 i.d., 0.500 o.d., and 3/32 balls). Use of R188-size bearings with this motor would require a special rotor shaft which considerably increases the cost of the motors. In addition, the time for delivery of the motors would be increased to three months - a prohibitively long time under the present irradiation schedule. Consequently, R3-size bearings will be utilized in the forthcoming bearing lubricant test. In a recent telephone conversation, Mr. David Rockray of Miniature Precision Bearing Company indicated that time-consuming difficulties might be encountered in applying solid-film lubricants to full-

complement bearings and suggested that it would be much better to use ribbon retainer bearings for the solid-film lubricants. In order to ensure that all the lubricants are subjected to the same load conditions in the bearings, ribbon retainer bearings will be used for all lubricants, excepting of course the Duroid or Rulon bearings.

Since five lubricants - namely, MLF-5, Duroid, G.E. F-50, Electrofilm 66C, and Shell ETR-H - are to be tested, ten control motors, ten motors for vacuum-irradiation, and two motors for equipment checkout have been ordered. Arrangements are being made to have all lubricants, except MLF-5 (which will be applied by MSFC), applied to the motor bearings by the Miniature Precision Bearing Company.

Because none of the vendors contacted (Kearfott, General Electric, Transco, Globe, and Bodine) could supply "off the shelf" a motor (other than an expensive gryo) with a sufficiently long coast-down time, it became necessary to select a motor which would meet all the other requirements, such as radiation and vacuum stability of the insulation of the stator windings, and to which a flywheel could be attached to increase the moment of inertia and thus the coast-down time. Experiments conducted at the IML have yielded information concerning the effects of bearing temperature and moment of inertia on the coast-down time of a similar servo motor and design of a flywheel for use in increasing the coast-down times of the R-112 motors for the vacuum-irradiation tests is being completed. Such a flywheel should have a moment of inertia of 300 gm-cm^2 and a weight of

from 1 to 2 oz. In the weight range of from 0 to 4 oz, bearing loading is expected to be insignificant for the R3-size bearing, provided the flywheel has been dynamically balanced. Each flywheel is to be attached to the motor shaft by means of a 7/0- by 3/8-inch taper pin through the shaft. It should be mentioned that care will be used in removing or attaching the flywheels, since any heavy blow will Brinell-damage the bearing races. An Alnico magnet 3/16 inch round and 5/8 inch long will be pressed in the flywheel to provide means for readout of coast-down. Coast-down times of about two minutes will be obtained with the flywheels.

To accommodate the larger motors and provide cooling water for the motors, it will be necessary to rework the motor rack. Extra electrical channels for the two additional motors required for the lubricant test this year can be provided through the existing Deutsch plugs in the vacuum system. Two additional power and electrical measurement networks, including milliammeters, will be added to the Bearing Lubricant Test control panel. Design of the water cooling system has not yet been completed.

III. COMBINED EFFECTS OF RADIATION AND CRYOTEMPERATURE

3.1 Test-Material Selection

The selection of materials for testing under Modification 3 to this contract was based upon previously observed properties of the materials (and/or families of materials) in various applications and environments. Desired properties and applications, with the order of importance for selection for testing in this experiment, are as follows:

1. Engineering properties suitable for use of the material in rocket vehicles. Retention of these properties at cryotemperatures. Retention of these properties after irradiation. Previous successful use in rocket vehicles.
2. Engineering properties suitable for use of the material in rocket vehicles. Retention of these properties at cryotemperatures. Possible (but not previously measured) retention of these properties after irradiation. Previous successful use in rocket vehicles.
3. Engineering properties suitable for use of material in rocket vehicles. Possible (but not previously measured) retention of these properties at cryotemperatures. Insignificant degradation of properties due to radiation. Previous successful use in rocket vehicles.
4. Engineering properties suitable for use of the material in rocket vehicles, and previous successful use in rocket vehicles.
5. Engineering properties suitable for use of the material in rocket vehicles.

Seven material categories were specified for testing in 1963 under Modification 3 to the contract. These categories are adhesives, structural laminates, seals, sealants, electrical insulations, thermal insulations, and potting compounds.

As noted above, the procedure used for selection of the materials was based upon a series of five combinations of desirable properties and applications with an order of importance to be used in the process of elimination. This series was used primarily as a reference in the selection procedure and not as an iron-clad rule, because other factors not listed could be influential in some cases.

One additional - and important - consideration was whether or not the material had been tested in the first year's work under the radiation-vacuum section of the original contract. If a material that was not tested under the radiation-cryotemperature environment during the first year has been tested under the radiation-vacuum section and had demonstrated good retention of its properties under this environment, then it would be a prime candidate for consideration at this time.

The materials which were selected, along with the scheduled tests, radiation doses, and specimen breakdown, are shown in Tables 3.1 through 3.11.

3.2 Test Plan

3.2.1 General

A tabulation of the materials and associated tests planned for this experiment is shown in Tables 3.1 through 3.7. Table 3.8 shows a breakdown of the materials and the number of specimens required for each run and each test. Table 3.9 shows the specimen and rod distribution for two assemblies for each low-temperature run (LN₂ and LH₂). Table 3.10 shows the specimen-mounting apparatus requirements for two

Table 3.1

Irradiation and Control Runs (Ambient, LN₂, LH₂): Adhesives

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote-Cyl. Operation	
A	Preirradiation (control)	Tensile-shear	ASTM D-1002-53T	-	3	Ambient	LN ₂ , LH ₂	Method of failure (adhesive or cohesive) will be determined by inspection
	Postirradiation	Tensile-shear	ASTM D-1002-53T	Low	3	Ambient	LN ₂ , LH ₂	
		Tensile-shear	ASTM D-1002-53T	High	3	Ambient	LN ₂ , LH ₂	
B	Preirradiation (control)	Tensile-shear	ASTM D-1002-53T	-	3	Ambient	LN ₂ , LH ₂	
	Postirradiation	Tensile-shear	ASTM D-1002-53T	Low	3	Ambient	LN ₂ , LH ₂	
		Tensile-shear	ASTM D-1002-53T	High	3	Ambient	LN ₂ , LH ₂	

Table 3.2

Irradiation and Control Runs (Ambient, LN₂, LH₂): Seals

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
C	Continuous	Leakage	See Fig. 4 FZP-363	0 to max.	2	-	-	FZP-363: A technical proposal to NASA titled: "Investigation of the Effects of Nuclear Radiation and Cryogenic Temperatures on Selected Alloys and Nonmetallic Materials"
D	Preirradiation (control)	Ult. tensile st. & elong.	ASTM D-638 -61T	-	3	Ambient	LN ₂ , LH ₂	
	Postirradiation	Ult. tensile st. & elong.	ASTM D-638 -61T	Low	3	Ambient	LN ₂ , LH ₂	
		Ult. tensile st. & elong.	ASTM D-638 -61T	High	3	Ambient	LN ₂ , LH ₂	

Table 3.3

Irradiation and Control Runs (Ambient, LN₂, LH₂): Thermal Insulations

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
E	Preirradiation (control)	Thermal conductivity	GD/FW-designed	-	-	Not required	Not required	One thermal conductivity measuring apparatus per material per test will be used.
	Postirradiation	Thermal conductivity	GD/FW-designed	Low	-	Not required	Not required	
		Thermal conductivity	GD/FW-designed	High	1	Not required	Not required	
F	Preirradiation (control)	Thermal conductivity	GD/FW-designed	-	-	Not required	Not required	
	Postirradiation	Thermal conductivity	GD/FW-designed	Low	-	Not required	Not required	
		Thermal conductivity	GD/FW-designed	High	1	Not required	Not required	
G	Preirradiation (control)	Thermal conductivity	GD/FW-designed	-	-	Not required	Not required	
	Postirradiation	Thermal conductivity	GD/FW-designed	Low	-	Not required	Not required	
		Thermal conductivity	GD/FW-designed	High	1	Not required	Not required	
	Preirradiation (control)	Thermal conductivity	GD/FW-designed	-	-	Not required	Not required	
	Postirradiation	Thermal conductivity	GD/FW-designed	Low	-	Not required	Not required	
		Thermal conductivity	GD/FW-designed	High	1	Not required	Not required	

Table 3.4

Irradiation and Control Runs (Ambient, LN₂, LH₂): Electrical Insulations

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
H	Preirradiation (control)	Stress-strain, ult. ten. & elong.	ASTM D-412-51T	-	4	Ambient	LN ₂ , LH ₂	"Direct Pull" on tensile machine refers to standard operation rather than remote cylinder pulling.
	Postirradiation	Stress-strain, ult. ten. & elong.	ASTM D-412-51T	Low	3	Ambient	LN ₂ , LH ₂	
		Stress-strain, ult. ten. & elong.	ASTM D-412-51T	High	3	Ambient	LN ₂ , LH ₂	
I	Preirradiation (control)	Stress-strain, ult. ten. & elong.	ASTM D-638-61T	-	3	Ambient	LN ₂ , LH ₂	GD/FW-designed thin-film testers will be used when applicable
	Postirradiation	Stress-strain, ult. ten. & elong.	ASTM D-638-61T	Low	3	Ambient	LN ₂ , LH ₂	
		Stress-strain, ult. ten. & elong.	ASTM D-638-61T	High	3	Ambient	LN ₂ , LH ₂	

Table 3.4 (cont'd)

Material	Test Classification	Test Type	Test Method	Inte-grated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
J	Preirradiation (control)	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	-	4	Ambient	LN ₂ , LH ₂	
	Postirradiation	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	Low	3	Ambient	LN ₂ , LH ₂	
		Stress-strain, ult.ten. & elong.	ASTM D-638-61T	High	3	Ambient	LN ₂ , LH ₂	

Table 3.5

Irradiation and Control Runs (Ambient, LN₂, LH₂): Structural Laminates

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
K	Preirradiation (control)	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	-	4	Ambient	LN ₂ , LH ₂	"Remote Cyl. Operation" refers to method of pulling samples remotely through use of a hydraulic servo-system using cylinders (See Fig. 1, FZP-363)
	Postirradiation	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	Low	3	Ambient	LH ₂ , LN ₂	
		Stress-strain, ult.ten. & elong.	ASTM D-638-61T	High	3	Ambient	LN ₂ , LH ₂	
L	Preirradiation (control)	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	-	4	Ambient	LN ₂ , LH ₂	
	Postirradiation	Stress-strain, ult.ten. & elong.	ASTM D-638-61T	Low	3-	Ambient	LN ₂ , LH ₂	
		Stress-strain, ult.ten. & elong.	ASTM D-638-61T	High	3	Ambient	LN ₂ , LH ₂	

Table 3.6

Irradiation and Control Runs (Ambient, LN₂, LH₂): Potting Compounds

Material	Classification	Test Type	Test Method	Inte- grated Dose	No. of Speci- mens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
M	Preirradiation (control)	Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	-	4	Ambient	LN ₂ , LH ₂	
	Postirradiation	Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	Low	4	Ambient	LN ₂ , LH ₂	
		Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	High	4	Ambient	LN ₂ , LH ₂	
N	Preirradiation (control)	Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	-	4	Ambient	LN ₂ , LH ₂	
	Postirradiation	Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	Low	4	Ambient	LN ₂ , LH ₂	
		Pull-out strength of potted wires	NASA-GD/FW- designed apparatus	High	4	Ambient	LN ₂ , LH ₂	

Table 3.7
Irradiation and Control Runs (Ambient, LN₂, LH₂): Sealants

Material	Test Classification	Test Type	Test Method	Integrated Dose	No. of Specimens (each run)	Tensile Mach. Appl.		Remarks
						Direct Pull	Remote Cyl. Operation	
O	Preirradiation (control)	T-peel	ASTM D-1876 -61T	-	4	Room temp.	Not used	
	Postirradiation	T-peel	ASTM D-1876 -61T	Low	3	Room temp.	Not used	
		T-peel	ASTM D-1876 -61T	High	3	Room temp.	Not used	
P	Preirradiation (control)	T-peel	ASTM D-1876 -61T	-	4	Room temp.	Not used	
	Postirradiation	T-peel	ASTM D-1876 -61T	Low	3	Room temp.	Not used	
		T-peel	ASTM D-1876 -61T	High	3	Room temp.	Not used	

Table 3.8

Test Specimen Breakdown and Summation

Matl. Desc.	Name Material	Material Manufacturer	Type of Specimen	Number of Specimens												Total
				Ambient Run			LN ₂ Run			LH ₂ Run						
				Con- trol	Low Dose	High Dose	Con- trol	Low Dose	High Dose	Con- trol	Low Dose	High Dose	Con- trol	Low Dose	High Dose	
A	AF-40	Minn. Mining & Mfg. Co.	Lap shear	4	4	4	3	3	3	3	3	3	3	3	3	30
B	Aerobond 422J	Adhesives Engr. Co.	Lap shear	4	4	4	3	3	3	3	3	3	3	3	3	30
C	Viton B	Precision Rubber Co.	O-ring (AN6230-2)	1	1	1	1	1	1	1	1	1	1	1	1	9
D	Polymer SP	E. I. du Pont	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30
E	Stafoam AA-402	Amer. Latex Products Co.	Thermal Conductivity	-	-	1	-	-	1	1	-	-	-	1	1	3
F	CPR-20	Chem. Plastics Research Co.	Thermal Conductivity	-	-	1	-	-	1	1	-	-	-	1	1	3
G	CPR-1021	Chem. Plastics	Thermal Conductivity	-	-	1	-	-	1	1	-	-	-	1	1	3
H	Geon 8800 w/polyester plasticizer	B. F. Goodrich Co.	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30
I	Duroid 5600	Rogers Corp.	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30
J	Millimenc-Glass 6038	Minn. Mining & Mfg. Co.	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30
K	CTL-91-LD	Eldon Fiber Glass Mfg.	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30
L	DC-2104 w/glass fabric	Dow Corning Mfg. Co.	Dumbbell	4	4	4	3	3	3	3	3	3	3	3	3	30

Table 3.8 (cont'd)

Matl. Desc.	Name of Material	Material Manufacturer	Type of Specimen	Number of Specimens												Total
				Ambient Run			LN ₂ Run			LH ₂ Run						
				Con- trol	Low Dose	High Dose	Con- trol	Low Dose	High Dose	Con- trol	Low Dose	High Dose				
M	Epon 828/Z	Shell Chemical	Potted wire tensile	4	4	4	4	4	4	4	4	4	4	4	36	
N	EC-2273B/A	Minn. Mining & Mfg. Co.	Potted wire tensile	4	4	4	4	4	4	4	4	4	4	4	36	
O	EC-1949	Minn. Mining & Mfg. Co.	T-peel	4	4	4	3	3	3	3	3	3	3	3	30	
P	EC-1663	Minn. Mining & Mfg. Co.	T-peel	4	4	4	3	3	3	3	3	3	3	3	30	
			TOTALS	49	49	52	39	39	42	39	39	42	39	42	390	

Table 3.9

Specimen and Rod Distribution: Two Assemblies (LN₂ or LH₂ Run)

Material Designation	Number of Specimens			Number of Rods Required
	Low Dose	High Dose	Total	
A	3	3	6	2
B	3	3	6	2
C	1	1	2	0
D	3	3	6	2
E		1	1	0
F		1	1	0
G		1	1	0
H	3	3	6	2
I	3	3	6	2
J	3	3	6	2
K	3	3	6	2
L	3	3	6	2
M	4	4	8	2
N	4	4	8	2
O	3	3	6	0
P	3	3	6	0
Totals	39	42	81	20

Note: One specimen each of materials O and P are used with specimens D, H, I, J, K, and L.

Table 3.10

Specimen-Mounting Apparatus Requirements:
Two Assemblies (LN₂ or LH₂ Run)

Type	Number Required
Standard Clevis with Lap-Shear Specimens	4
Standard Clevis with Dumbbell-Type Specimens	12
Standard Clevis with potting Compound Tester	4
Standard Clevis with T-Peel Specimens	0
TOTAL	20

Note: T-peel specimens will be included
with dumbbell-type specimens.

Table 3.11

Radiation Damage Levels

Material Category	Material	Gamma Dose ergs/gm(C)	
		To Product 10% Change in Measured Properties	To Produce 50% Change in Measured Properties
Adhesives	A & B	1(10)	5(10)
Seals	C & D	5(9)	1(10)
Thermal Insulations	E, F & G	5(9)	5(10)
Electrical Insulations	H & I	5(9)	1(10)
Electrical Insulations	J	1(10)	5(10)
Structural Laminates	K & L	1(10)	5(10)
Potting Compounds	M & N	5(9)	1(10)
Sealants	O	5(9)	1(10)
Sealants	P	1(10)	5(10)

Note: 1(10) 1 x 10¹⁰

assemblies in each of the low-temperature runs. Each material will be tested before irradiation at each of the three specified temperatures to establish control data points. Several specimens of each material will then be tested at these temperatures after receiving a low dose of nuclear radiation and again after having received a high dose.

Three different gamma doses will be required to establish low and high dose levels for each of the six different material categories covered in the experiment. The "low" dose is defined as that which will produce about a 10% change in the measured property of the material; the "high" dose, that which will produce about a 50% change. The two gamma doses that will be required to produce these two damage levels in each of the six material categories are shown in Table 3.11 and have been determined through a literature survey of currently available reports covering the effects of radiation on materials.

3.2.2 Test Equipment

3.2.2.1 Irradiation Facility

The GTR is a heterogeneous, highly enriched, thermal reactor which utilizes water as neutron moderator and reflector, as radiation shielding, and as coolant. Maximum power generation is three megawatts.

The irradiation pool is divided into two sections - one north, one south. The south section forms the reactor pool and is filled with water; the north section is the irradiation cell and is kept dry. The reactor closet, in the center of the pool divider, extends

into the irradiation cell so that three sides of the closet provide three irradiation positions. These positions are adjacent to the east, north, and west faces of the reactor closet.

Adjacent to the north wall of the irradiation cell is the handling area. Equipment permanently installed in the handling area includes a gas-monitoring system, a Davis explosion meter, and environmental conditioning equipment for the Radiation Effects Testing System. The auxiliary equipment necessary for the vacuum and cryogenic experiments was also located in this area.

The reactor closet is shrouded by $\frac{1}{4}$ -inch-thick boral to attenuate thermal neutrons. The boral extends 36 inches east and west along the pool divider from the closet and 36 inches up and down from the horizontal centerline of the reactor. The centerline is 57 inches above the cell floor.

The reactor, in an aluminum enclosure to facilitate cooling-water flow, is mounted on a horizontal positioning mechanism in the south position. This mechanism enables the reactor to be positioned at any distance from 2 to 90 inches from the north face of the closet.

An integral part of the NARF Radiation Effects Testing Facility is the shuttle system. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the reactor closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be

operated from either the control room or the dolly motor-driven shed on the north ramp. Full-coverage televising of the entire shuttle system is provided by means of a closed-circuit television system in the control room.

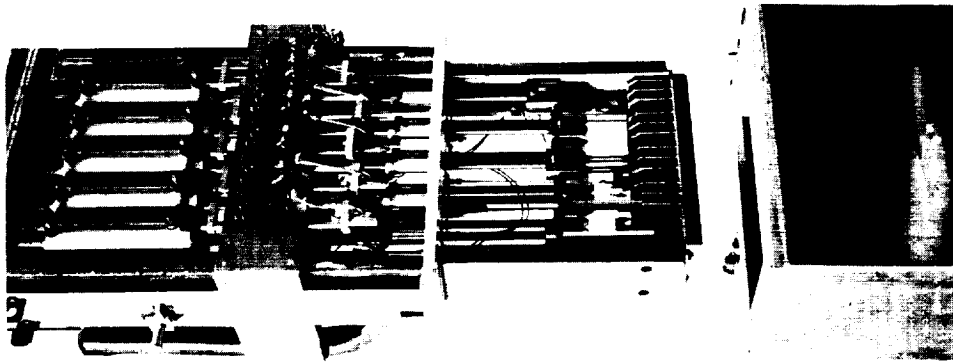
Cryotemperature and ambient temperature irradiation tests are performed on the east and north irradiation positions. The experimental assemblies and the ambient irradiation racks are secured on the dollies and lowered into position by means of the shuttle system.

3.2.2.2 Experimental Assemblies

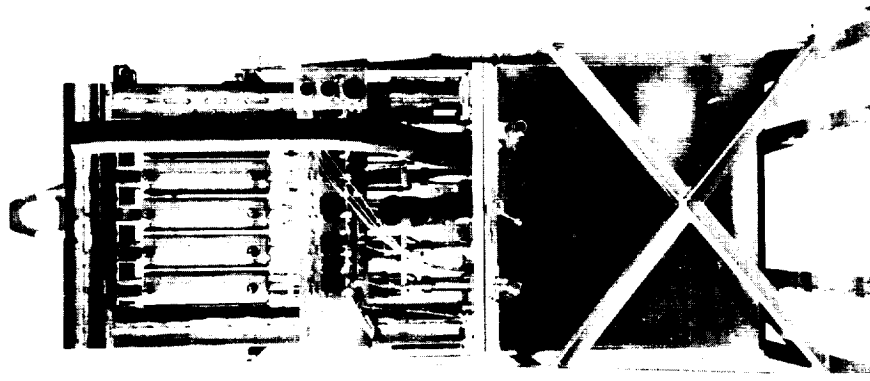
Three experimental assemblies consisting of cryogen Dewars and associated tensile-pulling apparatus were designed and constructed at GD/FW (Fig. 3.1). Two of these will be used for each low-temperature irradiation and associated tests. All samples (control and irradiated) to be tested at LN₂ and LH₂ temperatures will be tested while submerged in the cryogen in these experimental assemblies. Tensile and compression testing of these samples will be effected by piston movement in hydraulic cylinders located in the top section of the assemblies. A master cylinder will be operated by the Instron crosshead, and flexible fluid lines will transmit fluid pressure from the Instron cylinder to the slave cylinders on the remotely located experimental assemblies. Stress-strain data will be recorded by the Instron machine and other instrumentation.

3.2.2.3 Seal Leakage Tester

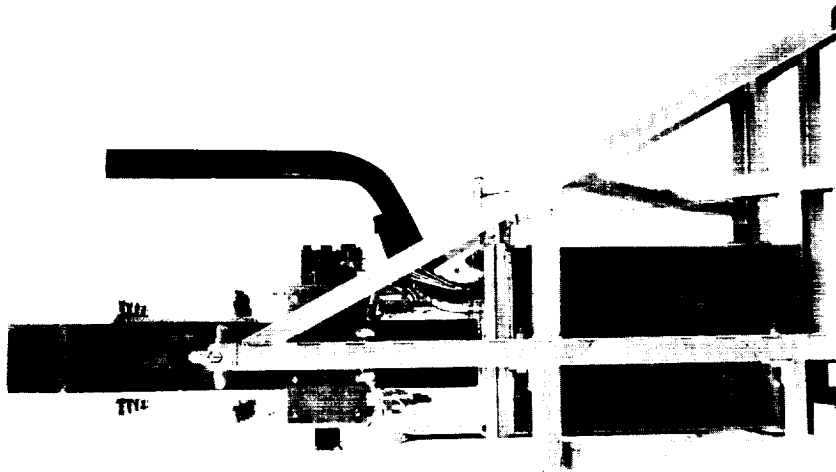
The seal leakage test will be carried out with the use of a pressure chamber sealed with an O-ring made from the material to be



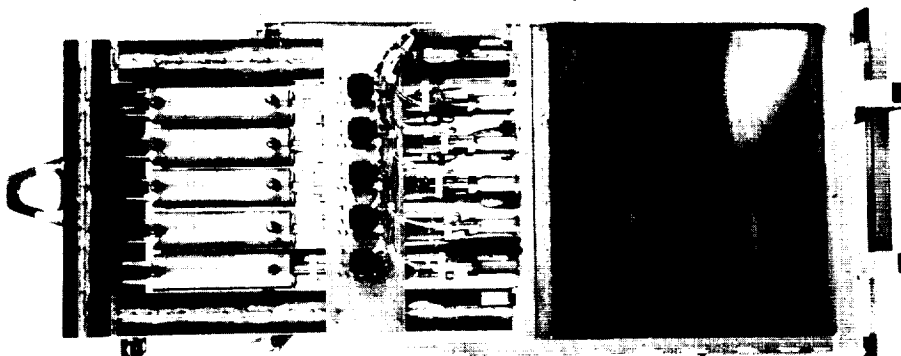
Separated



Back



Side



Front

Figure 3.1 Various Views of Experimental Assembly

tested. The chamber will be pressurized with helium gas and pressure changes monitored during the irradiation. Pressure, as a function of time, will be recorded to determine leakage rates through the seal. The chamber will be located in the ambient-irradiation box during the ambient-irradiation run and will be submerged in the cryogen during the low-temperature irradiation runs.

3.2.2.4 Thermal Conductivity Tester

The thermal conductivity test will utilize test apparatus designed around the cylindrical geometry approach for determination of k . Three concentric cylinders are used, with the inner cylinder containing a test heater and two guard heaters. The middle cylinder is the test material and the outer cylinder is the outer casing for the device. The inner and outer cylinders are made from pure copper. A controlled supply of heat will be added to the test specimen with the test heater and a resulting Δt will be monitored radially through the test material. Steady-state data will be used in the calculation of the coefficient of thermal conductivity k . Figures 3.2 and 3.3 are cross-sectional views of the tester. Figure 3.4 shows how the device is attached to the underside of the cryogen chamber top plate.

Figure 3.2 shows the test specimen to have an effective length, l , of five inches; it also shows the location of the test heater as a coil of wire wrapped in grooves on the inner cylinder. The relatively small value of l requires a guard heater on each end of the assembly to ensure radial distribution of all of the heat generated in the test heater.

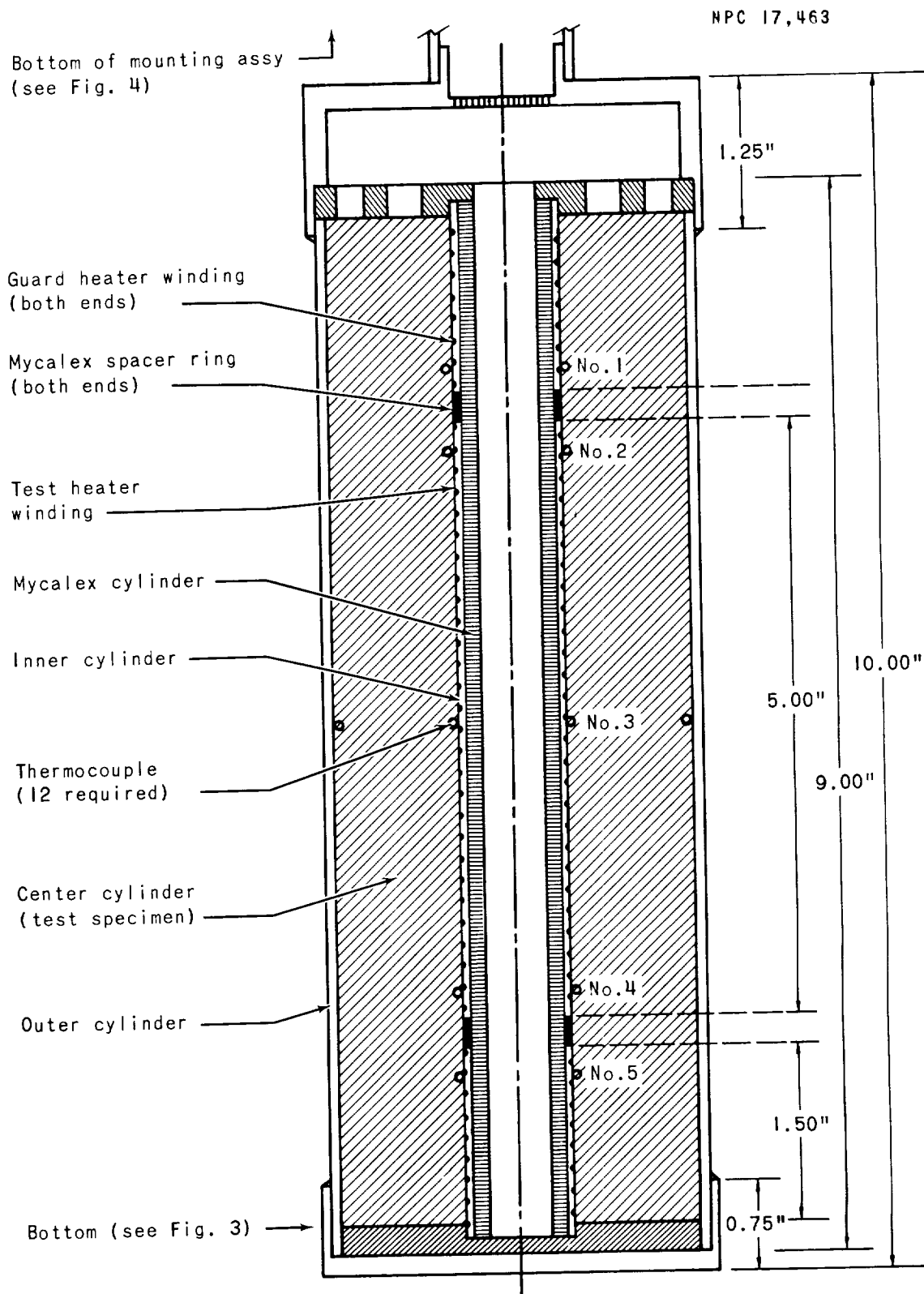


Figure 3.2 Thermal-Conductivity Tester

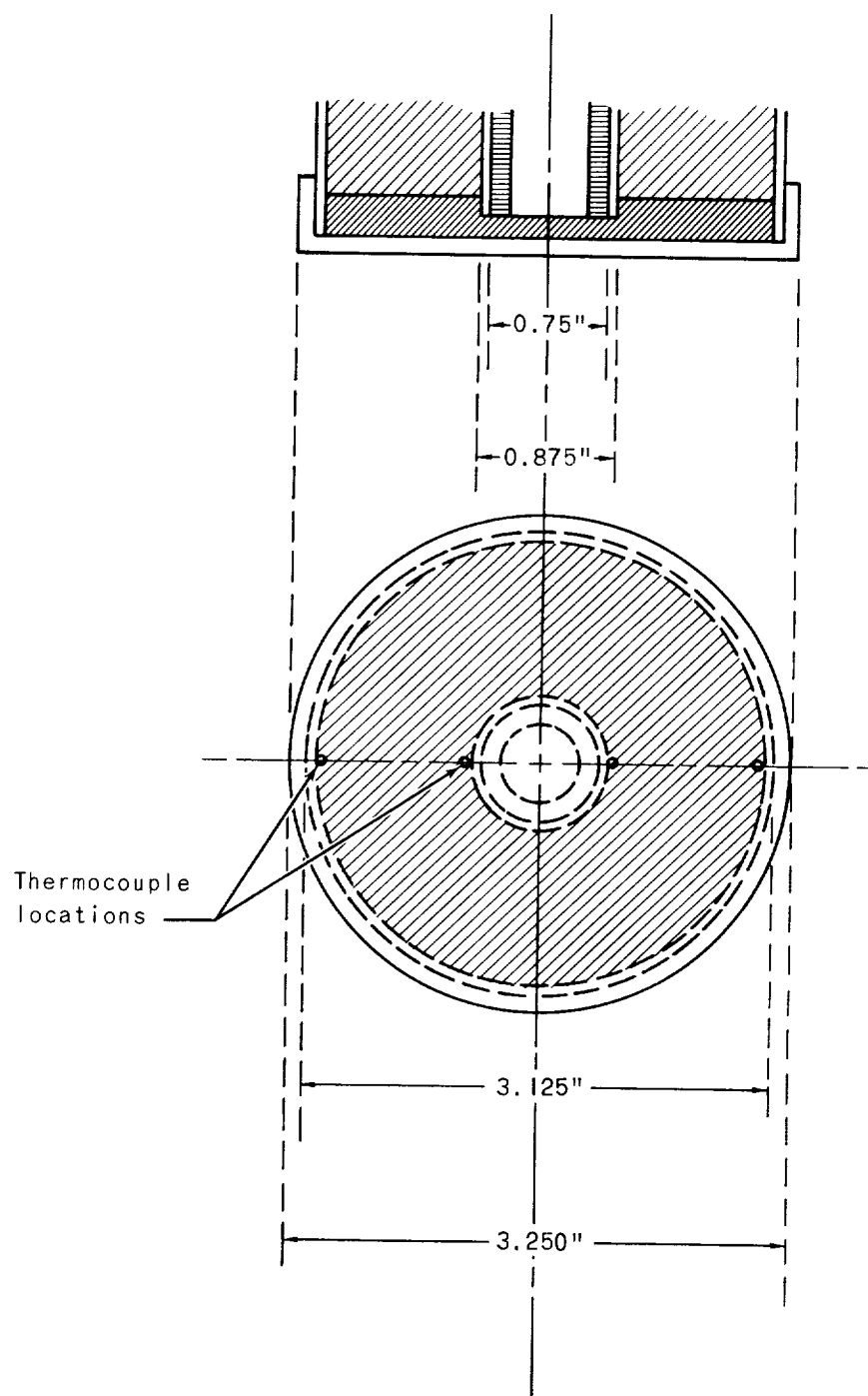


Figure 3.3 Bottom View of Thermal-Conductivity Tester

Five groups of thermocouples are used. Each group contains two thermocouples mounted in a plane and spaced 180° apart on the outside of the inner cylinder. Groups 2, 3, and 4 are used to record the temperature of the inner cylinder (t_1 in the equations shown in the appendix). The six recorded data points are averaged to arrive at a mean value for t_1 .

Groups 1 and 5 are used to monitor the temperature of the end (or guard) sections of the inner cylinder. Power to the guard heaters is varied during a test to ensure that the average of temperatures recorded for thermocouples in Groups 1 and 5 matches, respectively, the average of those recorded for thermocouples in Groups 2 and 4. This ensures the radial distribution of all energy generated by the test heater. Two additional thermocouples in Group 3 are used to monitor the temperature of the test specimen at the inner surface of the outer cylinder.

During a test, the entire assembly is submerged in boiling cryogen (either LN_2 or LH_2). Because of the relatively high value of k for the outer-cylinder material, the temperature of the outer surface of the test material is considered to be equal to the outside temperature of the outer cylinder. (This is t_4 in the equations in the appendix.) A check on this is maintained by readings from the outer thermocouples in Group 3. The value of x in the equation is equal to the thickness of test material between the inner and outer cylinders.

The end caps for the assembly are made from pure copper. The end insulators, the core for the inner copper cylinder, and the inner-cylinder spacers are made from Mycalex, a glass-bonded mica with a k value of ~ 0.001 . The heater wire is fiberglass-covered constantan. This wire has a diameter of 0.003 inch and a resistance of 29 ohms/foot.

Figure 3.4 shows a connecting tube from the test assembly to the top flange of the experimental assembly. This tube serves to support the test assembly and to furnish a housing for heater and thermocouple leads. It should be noted that the arrangement provides for a portion of this tube to be submerged in cryogen during operation, thus furnishing a heat sink for heat being conducted from outside the experimental assembly, through the electrical leads, to the thermal conductivity test assembly.

Power is supplied to the heaters by a regulated dc source. The power can be varied manually. A Leeds-Northrup K-2 potentiometer is used to measure millivolt output of the thermocouples.

The technique for making a k -value measurement involves the gradual application of heat to the test and guard heaters until t_1 (measured by thermocouple Groups 2, 3, and 4) exceeds t_4 (known temperature of the boiling cryogen) by about 20°K . After a reasonable stabilization time is allowed, the temperatures are recorded, averaged, and substituted into the proper equation for k_{m2} (k for the test specimen).

Data are also taken for other temperature intervals. Values for k_{m2} are reported in engineering units of $\text{Btu-in/ft}^2\text{-hr-}^\circ\text{F}$. The density of the test material is also reported.

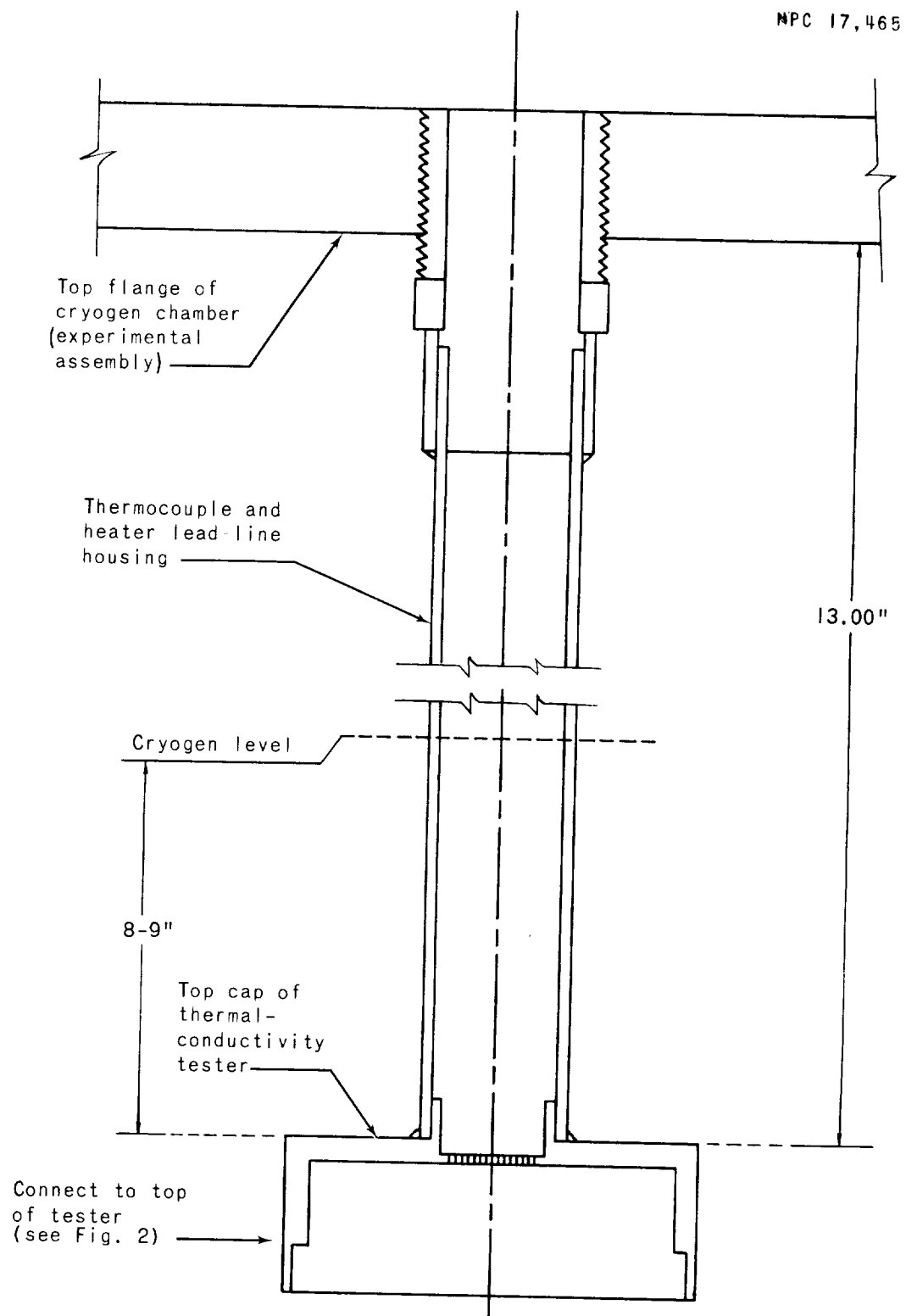


Figure 3.4 Mounting Assembly for Thermal-Conductivity Tester

A theoretical analysis of the cylindrical geometry approach for the determination of the coefficient of thermal conductivity of an insulating material is shown in the appendix.

3.2.3 Test Specimens

Dumbbell-type and lap-shear-type tensile specimens for non-metallic materials to be tested in this experiment will all require doublers on the ends for added strength. These doublers will be glued and/or riveted in place. A description of the lap-shear specimens, showing dimensions and arrangement of the doublers, is shown in Figures 3.5 and 3.6. Any thin-film tensile specimens which might be used will be cut according to ASTM dictates, except that the width will be increased to approximately $1\frac{1}{2}$ inches. Figures 3.7 and 3.8 show details of the two different dumbbell-type specimens to be used. Figure 3.9 is a description of the potted-wire tester, and Figure 3.10 a description of the T-peel tester.

Both specimens and tests in this experiment will comply as closely as possible with standard ASTM procedures. The appropriate ASTM standards for the scheduled tests are shown in the "Test Method" column of Tables 3.1 through 3.7.

3.2.4 Irradiation Test

Chronological order of the irradiation tests will be: (1) ambient-temperature run, (2) liquid-nitrogen run, and (3) liquid-hydrogen run. In each run, the reactor will operate continuously at prescribed power levels sufficient to produce the anticipated changes in the engineering properties of the materials. The reactor

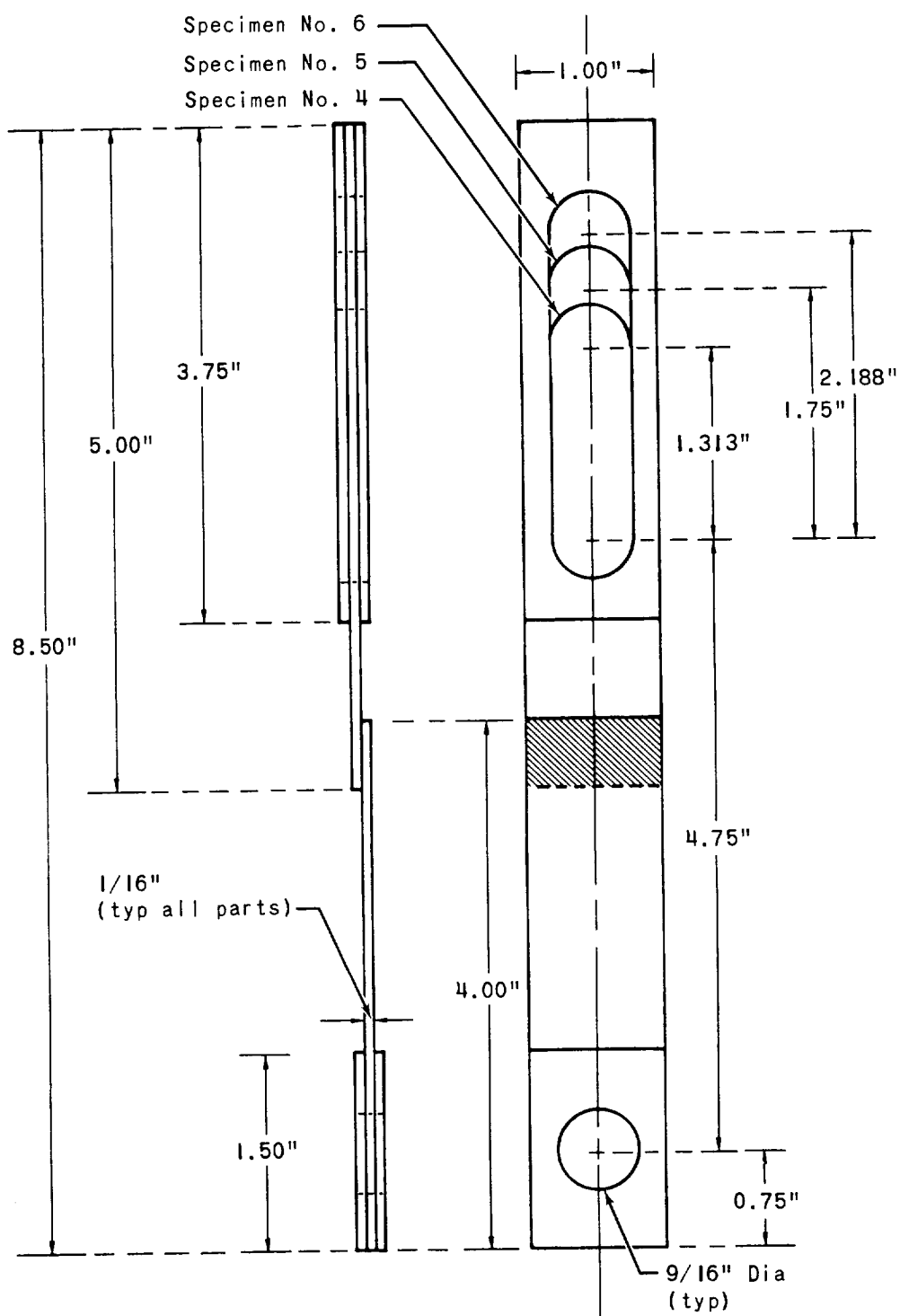


Figure 3.5 Lap-Shear Specimen: Material A

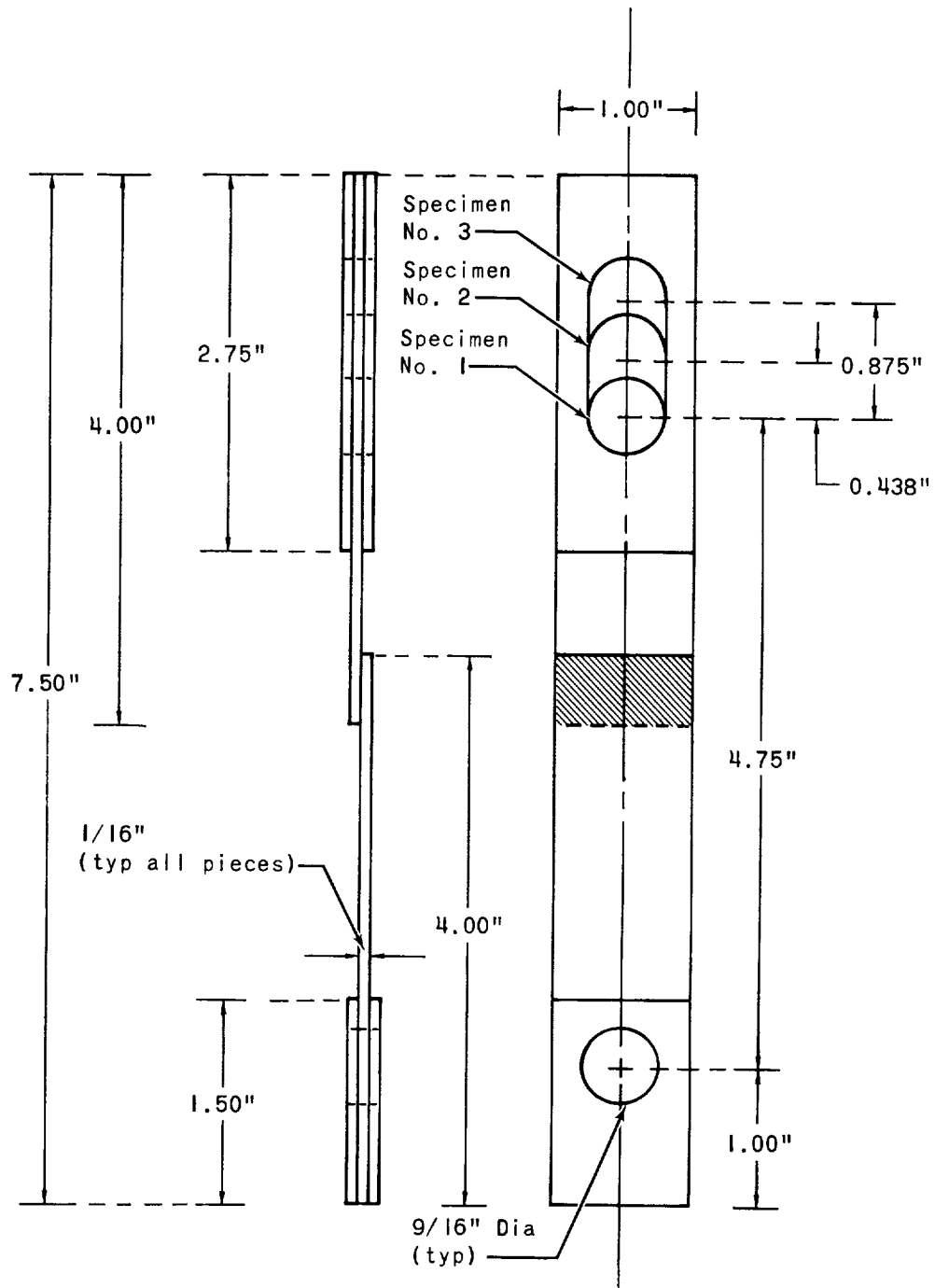


Figure 3.6 Lap-Shear Specimen: Material B

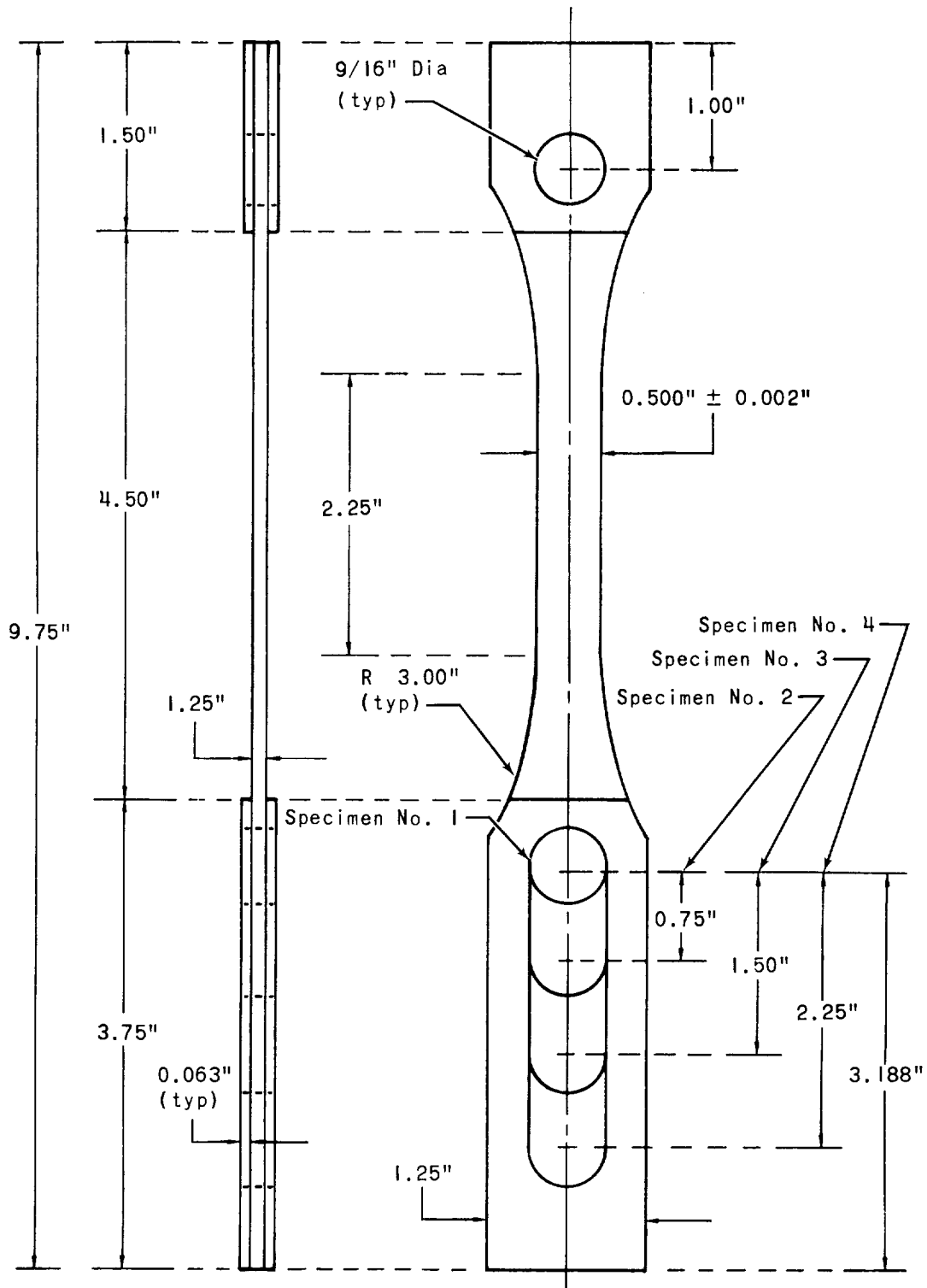


Figure 3.7 Dumbbell-Type Specimen: Materials D, H, and I

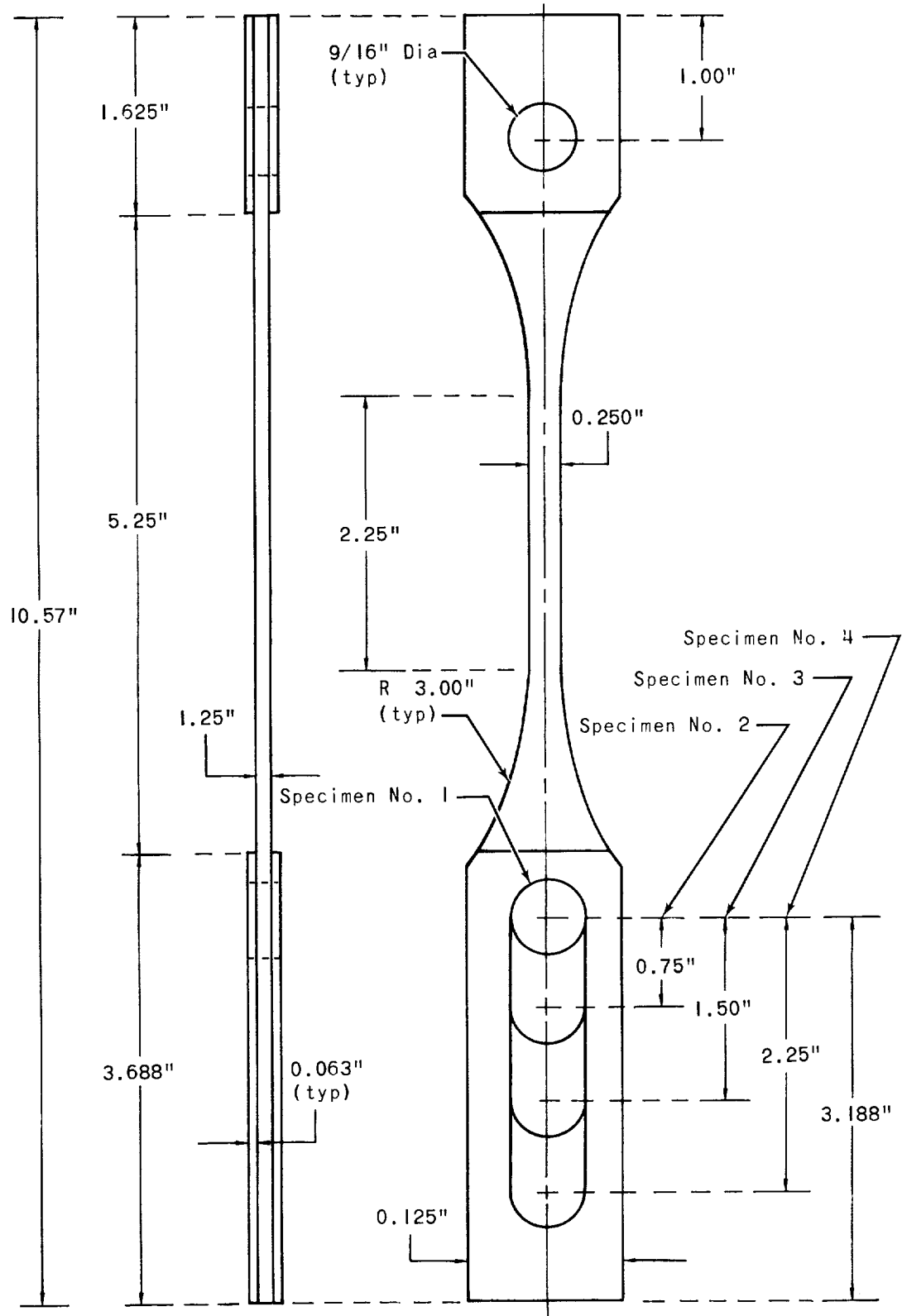


Figure 3.8 Dumbbell-Type Specimen: Materials J, K, and L

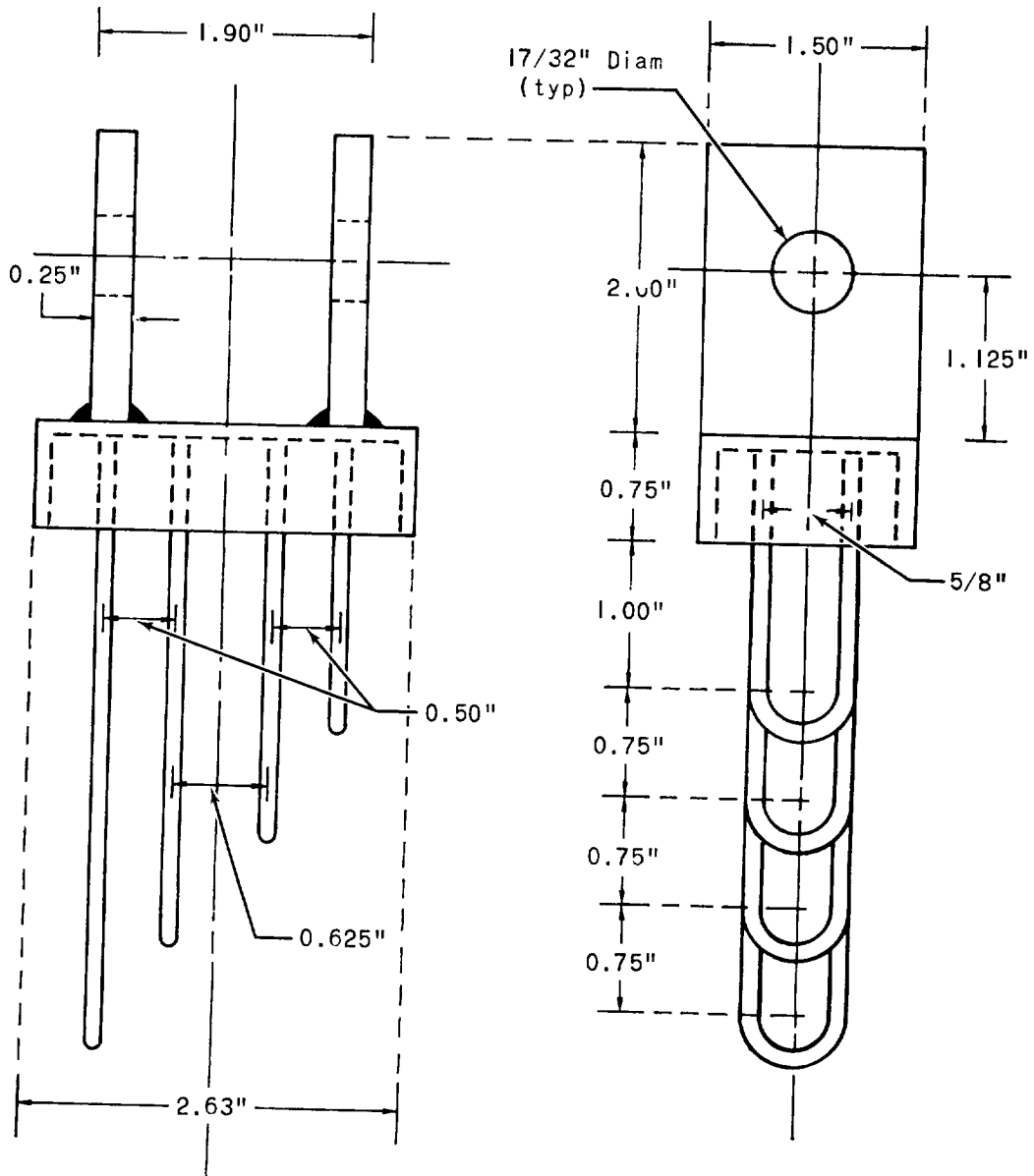


Figure 3.9 Potted-Wire Tester: Materials M and N

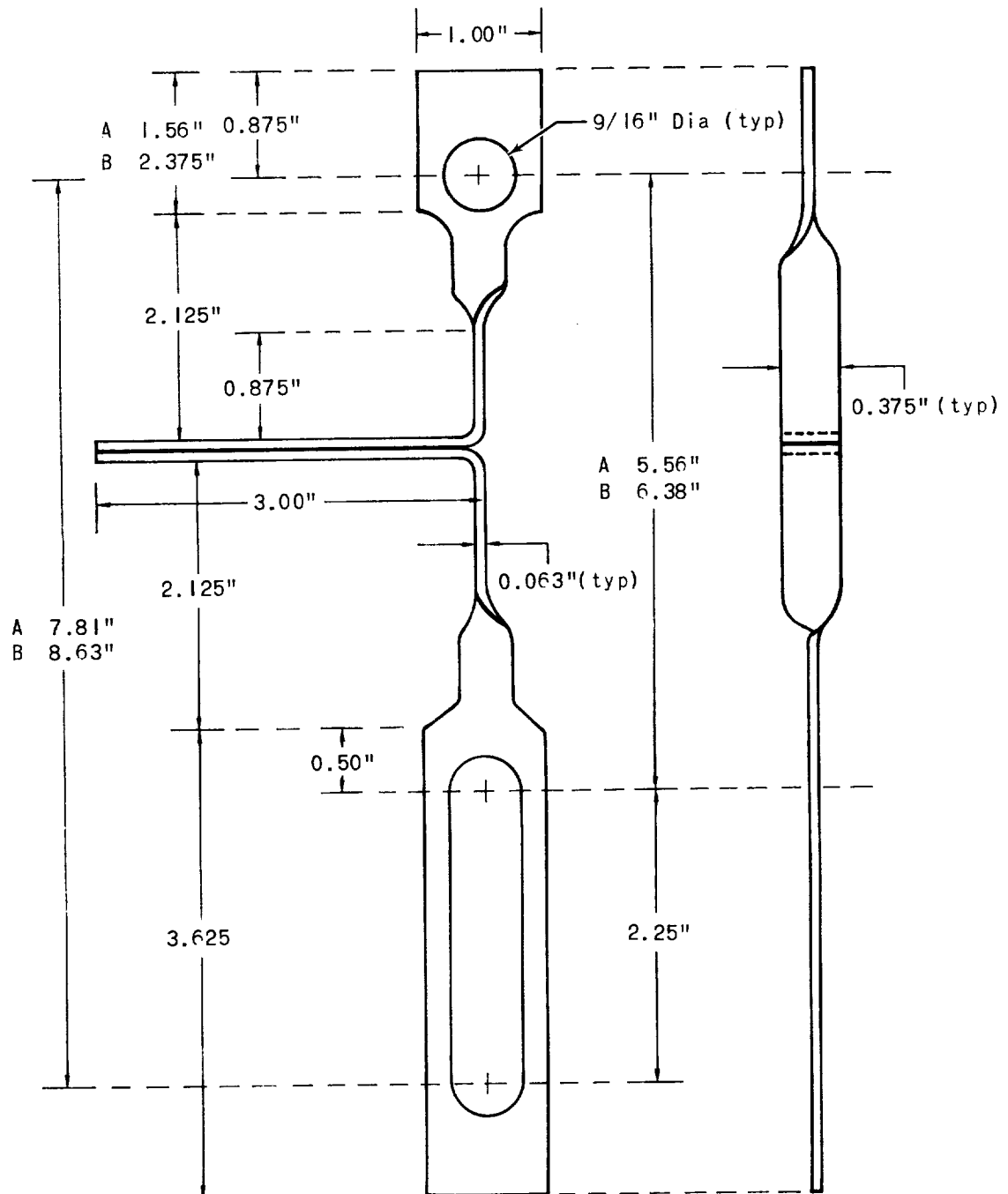


Figure 3.10 T-Peel Tester (Type A & B): Materials O and P

will then be retracted and material tests made. Maximum irradiation time for each run is estimated to be about 50 hours.

In the ambient-temperature run, a framework with associated trays will be used to position material specimens next to the reactor. The specimens will be mounted on expanded-metal racks and arranged in a spatial distribution (with respect to the reactor core) that will provide the required doses to the specimens. Neutron and gamma radiation fluxes incident on the specimens will be monitored with suitable dosimetry during the run. Pre- and post-irradiation testing of the ambient specimens will be done in the IML.

For the low-temperature runs, the experimental assemblies will be positioned next to the reactor core and continuously supplied with cryogen from a nearby tank truck. The Instron machine will be located in the shielded control room during these runs, and the samples will be tested while still submerged in the cryogen, after the 10% and 50% degradation levels, with the use of the hydraulic servosystem. Gamma and neutron fluxes will be measured at various points in the cryogen chamber during these irradiations.

Figure 3.11 is a layout of the irradiation positions, and shows how each position will be utilized during the four weeks of irradiations planned for the radiation-cryotemperature and radiation-vacuum tests.

3.3 Nuclear Measurements Plan

3.3.1 Ambient Irradiation

The ambient irradiation of material specimens will be made with

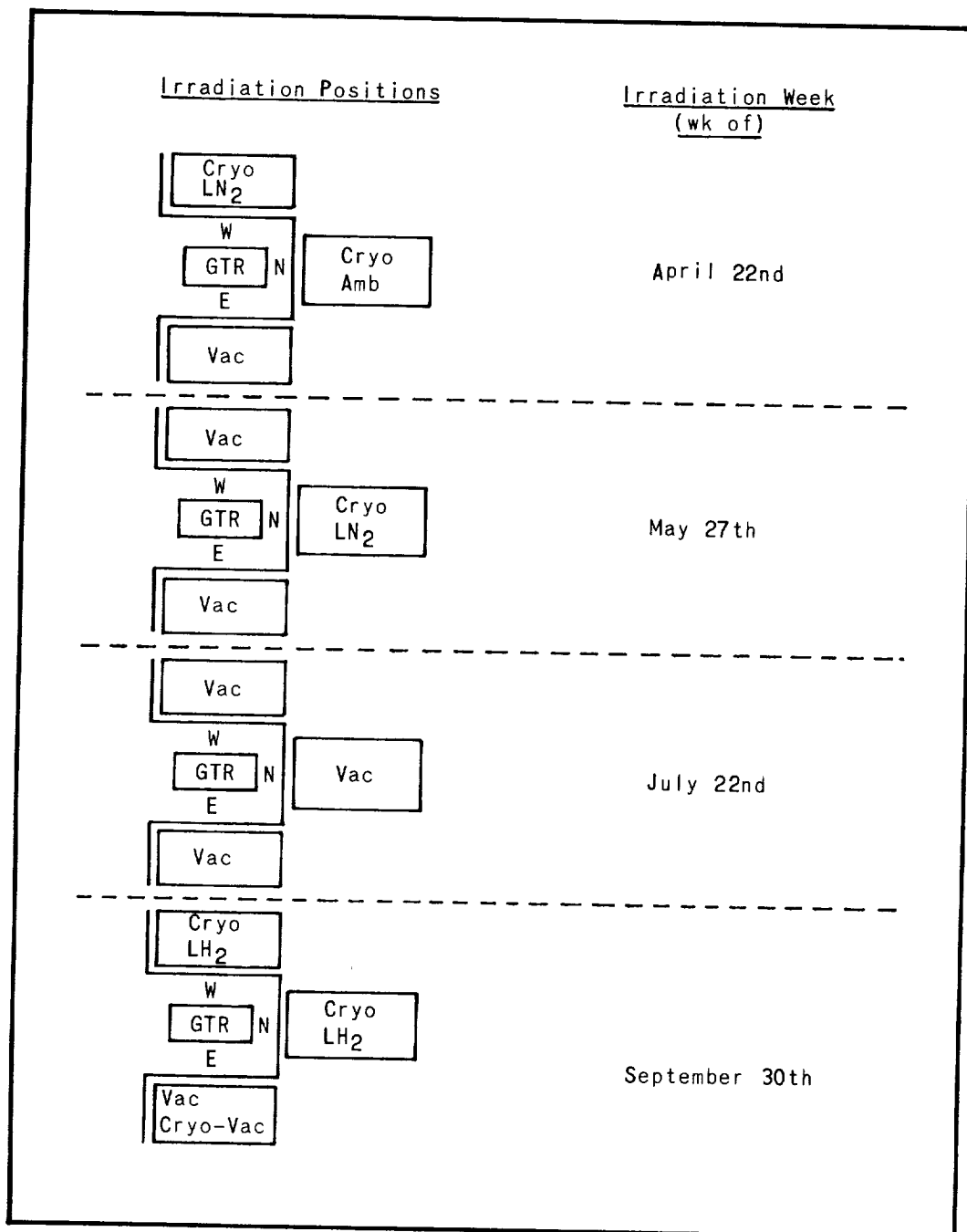


Figure 3.11 Irradiation-Position Breakdown for Four Weeks of Irradiations Scheduled for Radiation-Cryotemperature and Radiation-Vacuum Tests

the GTR shuttle system on the north irradiation position. Nuclear measurement packets will be placed at strategic locations on the racks upon which material samples will be mounted. Each packet will contain thermal-neutron foil detectors, a threshold detector, and a nitrous-oxide gamma dosimeter. No rack will contain less than five measurements packets.

3.3.2 LN₂ Irradiation

For this series of experiments, cryogen chambers will be located on both the north and east pallet positions. Nuclear-radiation measurement requirements for each of the cryogen chambers are identical and are outlined below.

1. Inside the Chamber:

- a. Two packets are located at each of the five pull-rod positions - one in front of and one behind material sample groups. Total: ten packets.
- b. Each packet will consist of thermal neutron detectors and two high energy threshold detectors.

2. Outside the Chamber:

- a. A total of six packets will be used - three on the front face and three on the back face of the Dewar. The packets will be mounted opposite pull rods 1, 3, and 5, on a plane through the material sample centers.
- b. A packet will consist of thermal-neutron detectors, a high energy threshold detector and a gamma dosimeter.

3.3.3 LH₂ Irradiation

The series of experiments in which material samples are to be irradiated at LH₂ temperatures will be conducted on the north and east pallet positions. Nuclear radiation measurements will be made

in the same manner as that outlined for the LN_2 experiments with regard to the number of detector packets, the location of packets inside and outside the experimental assemblies, and the number and type of radiation detector on each packet.

IV. COMBINED EFFECTS OF RADIATION, VACUUM, AND CRYOTEMPERATURE

A program has been initiated to evaluate the combined effects of radiation, vacuum, and cryotemperatures on selected engineering materials. Since a program of this type has received little or no previous consideration and since many nuclear-vehicle materials will have applications in which they will be exposed to such a combination of environments, a program of this nature forms a logical and necessary extension of the work described in Sections II and III.

4.1 Test Plan

The selection of the materials for these tests will be based on the results from the vacuum-radiation tests and the cryotemperature-radiation tests presented in the annual reports (Refs. 1 and 2) and from the tests presented in this report and scheduled for April 1963. These materials will be chosen from the categories of electrical insulations, dielectric materials, sealants, and potting compounds. Four materials will be selected from two of the above categories for testing in the triple environments.

Two dynamic testers will be built to test the materials at the termination of a radiation exposure while temperature and vacuum are maintained at the specified value. These are (1) the Electrical Tester to measure dielectric constant and dissipation factor and (2) the Mechanical Tester to measure stress-strain properties.

The Electrical Tester is being designed and constructed by NASA at the George C. Marshall Space Flight Center under the direction of R. L. Gause. This unit, designed to fit the vacuum-irradiation chambers, is patterned after a unit developed by Gause for testing in vacuum at liquid-helium temperatures. Radiation tests are scheduled to be made in air and in vacuum at liquid-nitrogen and liquid-hydrogen temperatures.

The Mechanical Tester will be patterned after the High-Force Tester used in the vacuum tests. This unit will have a shroud around the test samples which will contain the cryogen. One irradiation at liquid-hydrogen temperature is scheduled for this unit.

4.2 Nuclear-Radiation-Level Measurements for the Vacuum-Cryotemperature Irradiation System

During the irradiations that are scheduled for the vacuum-cryotemperature tests, nuclear measurements will be made to conform to the environmental conditions within the test volume, specifically with respect to the cryotemperature and high vacuum. This environment and the period of testing impose certain limitations upon the choice of detectors for neutron flux and gamma dose measurements.

4.2.1 Neutron Flux and Spectrum Monitoring

Each detector packet will contain four neutron detectors. The thermal-neutron flux will be measured by the cadmium difference method, which accounts for neutrons of energies $E > 0.48$ ev. For this purpose, bare- and cadmium-covered copper will be used.

The fast-neutron flux - namely, all neutrons with energies above 2.9 Mev - will be measured with two detectors, sulphur and aluminum. The nominal threshold energies for the appropriate reactions are 2.0 and 8.1 Mev, respectively. The sulphur will be contained in a pellet consisting of epoxy resin and 4% sulphur.

4.2.2 Gamma Dose Measurement

For gamma dose measurements at ambient temperatures, the TCE and N₂O dosimeters are used reliably. At cryotemperature, however, each of these dosimeters has characteristics which preclude their use. TCE and N₂O dosimeters lack response and normalization data during exposure to gamma radiation at cryotemperature.

Reliable estimates of the gamma dose inside the chamber can be obtained, however, by exposing TCE or N₂O dosimeters outside the chamber at the front and back, and interpolating between the two. This method will be used for monitoring during radiation tests.

4.2.3 Summary

The nuclear radiation measurements outlined for this group of experiments will be made using standard and accepted methods and utilizing the practices which have been developed through previous experiments at this facility. Data reduction will be accomplished using standard practices as outlined in References 20 and 21.

APPENDIX

DETERMINATION OF THE COEFFICIENT OF THERMAL CONDUCTIVITY OF AN INSULATING MATERIAL BY THE CYLINDRICAL GEOMETRY APPROACH

In general, insulating material may be considered to consist of small air spaces surrounded by solid walls. The low thermal conductivity of such materials may be attributed to the low thermal conductivity of the air enclosed within the interstices, or cells, of the material and the relatively small area of solid material through which the heat may be conducted.

Some differences in the value of the coefficient of thermal conductivity k for these types of materials may exist as a function of variable convective air currents within the cells, which, in turn, are affected by varying values of temperature difference (ΔT) across the thickness of material. Thus, a greater ΔT across the material will cause greater convective currents and increase the overall value of k .

The coefficient of thermal conductivity is defined as the quantity of heat that will flow across unit area in unit time if the temperature gradient between the two surfaces through which heat is flowing is unity.

For heat flow through the flat surfaces of a material of thickness x , with flow perpendicular to the surface, the following relations are thus established:

q/A = rate of heat flow through a unit area of the surface,

k = coefficient of thermal conductivity,

x = thickness of the material, and

$T_1 - T_2 = \Delta T$ across the thickness x (T_1 being the higher temperature).

Then $q/A = \frac{k}{x} (T_1 - T_2).$

The coefficient of thermal conductivity can also be defined as the proportionality constant between the heat per unit area per unit time crossing a point and the temperature gradient. Thus, for an isotropic medium,

$$\frac{d(q/A)}{dt} = -k \cdot \Delta T.$$

The temperature gradient through a material can be expressed as the rate of change of temperature with change of distance (dt/dL) and is always measured in the direction of flow. Then, the rate of heat transmission by conduction across an area, A , of any homogeneous material, for the steady-state condition, is given by Fourier's law as

$$q = -kA \frac{dt}{dL},$$

where the temperature is now represented by t .

The sign $(-)$ is used to give a positive value to q , (since the temperature change in the direction of flow is negative.

Integrating the above equation,

$$q \int_{L_1}^{L_2} \frac{dL}{A} = - \int_{t_1}^{t_2} k dt.$$

Now k will vary with temperature, or

$$k = f(t),$$

so that

$$q \int_{L_1}^{L_2} \frac{dL}{A} = - \int_{t_1}^{t_2} f(t) dt.$$

Multiplying and dividing the right hand side by $(t_2 - t_1)$,

$$q \int_{L_1}^{L_2} \frac{dL}{A} = \frac{- \int_{t_1}^{t_2} f(t) dt}{t_2 - t_1} (t_2 - t_1);$$

but the term

$$\frac{\int_{t_1}^{t_2} f(t) dt}{t_2 - t_1}$$

is the mean value of $f(t)$ between t_1 and t_2 , which in this case is equal to k_m , the mean value of k over this temperature range.

Therefore,

$$q \int_{L_1}^{L_2} \frac{dL}{A} = - k_m (t_2 - t_1)$$

or

$$q = \frac{k_m (t_1 - t_2)}{\int_{L_1}^{L_2} \frac{dL}{A}}.$$

Hence, without error, the term

$$- \int_{t_1}^{t_2} k dt$$

has been replaced by $k_m(t_1 - t_2)$, irrespective of the relation between A and L .

Now

$$q = \frac{k_m (t_1 - t_2)}{\int_{L_1}^{L_2} \frac{dL}{A}}$$

$$= \frac{(t_1 - t_2)}{\frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}}$$

and, comparable to Ohm's law in electrical circuits,

$$I = \frac{E}{R},$$

the term

$$\frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}$$

can be regarded as the thermal resistance, or R_t .

Then,

$$R_t = \frac{t_1 - t_2}{q}, \text{ or } q = \frac{t_1 - t_2}{R_t}$$

For conduction through thick-walled cylinders (two-dimensional, or radial, conduction; see Figure A-1), the area A for an annulus of length $\ell = 2\pi r\ell$.

The thickness of the annulus is $dr (= dL)$,

so that

$$R_t = \frac{1}{k_m} \int_{L_1}^{L_2} \frac{dL}{A}$$

$$= \frac{1}{k_m} \int_{r_1}^{r_2} \frac{dr}{2\pi\ell r} = \frac{1}{2\pi\ell k_m} \ln \frac{r_2}{r_1}.$$

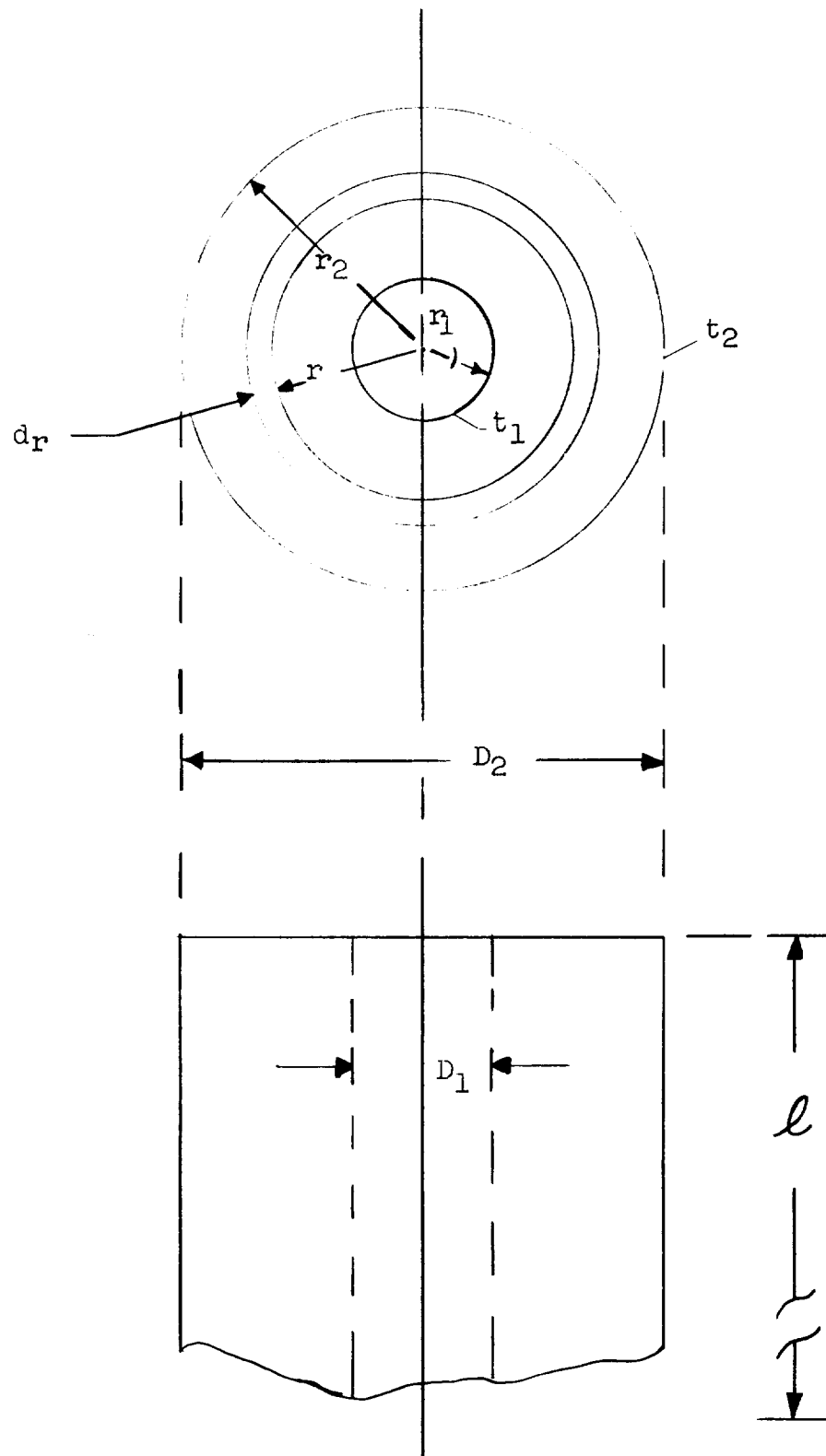


Figure A-1. Basic Cylindrical Geometry

If R_t is substituted back in the above equation for q and the diameter ratio is substituted for r_2/r_1 ,

then

$$q = \frac{2\pi \ell n k_m (t_1 - t_2)}{\ln(D_2/D_1)} .$$

If concentric cylinders of different materials are used, the composite thermal resistance is equal to a summation of the individual resistances. In other words, it represents, in the electrical analog, a series system.

Therefore, if there are three concentric cylinders, consisting of an inner sleeve, center sleeve (or test specimen), and outer sleeve (Fig. A-2),

$$q = \frac{2\pi \ell (t_1 - t_4)}{\frac{1}{k_{m1}} \ln \frac{D_2}{D_1} + \frac{1}{k_{m2}} \ln \frac{D_3}{D_2} + \frac{1}{k_{m3}} \ln \frac{D_4}{D_3}} ,$$

and if the inner sleeve is made of the same material as the outer sleeve,

$$k_{m1} \cong k_{m3}$$

and

$$q = \frac{2\pi \ell (t_1 - t_4)}{\frac{1}{k_{m1}} \left(\ln \frac{D_2}{D_1} + \ln \frac{D_4}{D_3} \right) + \frac{1}{k_{m2}} \ln \frac{D_3}{D_2}} ,$$

where $k_{m1} = k$ for inner sleeve (or cylinder)

$k_{m2} = k$ for center sleeve (or test specimen)

$k_{m3} = k$ for outer sleeve (or cylinder)

then,

$$\frac{1}{k_{m1}} \left(\ln \frac{D_2}{D_1} + \ln \frac{D_4}{D_3} \right) + \frac{1}{k_{m1}} \ln \frac{D_3}{D_2} = \frac{2\pi l(t_1 - t_4)}{q}$$

and

$$\frac{1}{k_{m2}} \ln \frac{D_3}{D_4} = \frac{2\pi l(t_1 - t_4)}{q} - \frac{1}{k_{m1}} \left(\ln \frac{D_2}{D_1} + \ln \frac{D_4}{D_3} \right).$$

thus

$$\frac{1}{k_{m2}} = \frac{\frac{2\pi l(t_1 - t_4)}{q} - \frac{1}{k_{m1}} \left(\ln \frac{D_2 D_4}{D_1 D_3} \right)}{\ln \frac{D_3}{D_2}},$$

or

$$k_{m2} = \frac{\ln \frac{D_3}{D_2}}{\frac{2\pi l(t_1 - t_4)}{q} - \frac{1}{k_{m1}} \left(\ln \frac{D_2 D_4}{D_1 D_3} \right)}.$$

The planned test involves the measurement of k for various foam-type thermal insulation materials at cryotemperatures. A system of three concentric cylinders are used (Fig. A-2). The inner and outer cylinders (or sleeves) are made from pure copper. The center cylinder is foamed-in-place test material. From this, it can be seen that $k_{m1} \gg k_{m2}$. (An approximate value for k_{m1}/k_{m2} is 10,000.) Also, the term

$$\frac{D_2 D_4}{D_1 D_3}$$

in the above equations is approximately 1.8. So, for all practical purposes,

$$\frac{1}{k_{m1}} \cdot \ln \left(\frac{D_2 D_4}{D_1 D_3} \right) = 0.$$

Therefore, for this test,

$$k_{m2} = \frac{q \left(\ln \frac{D_3}{D_2} \right)}{2\pi l(t_1 - t_4)}.$$

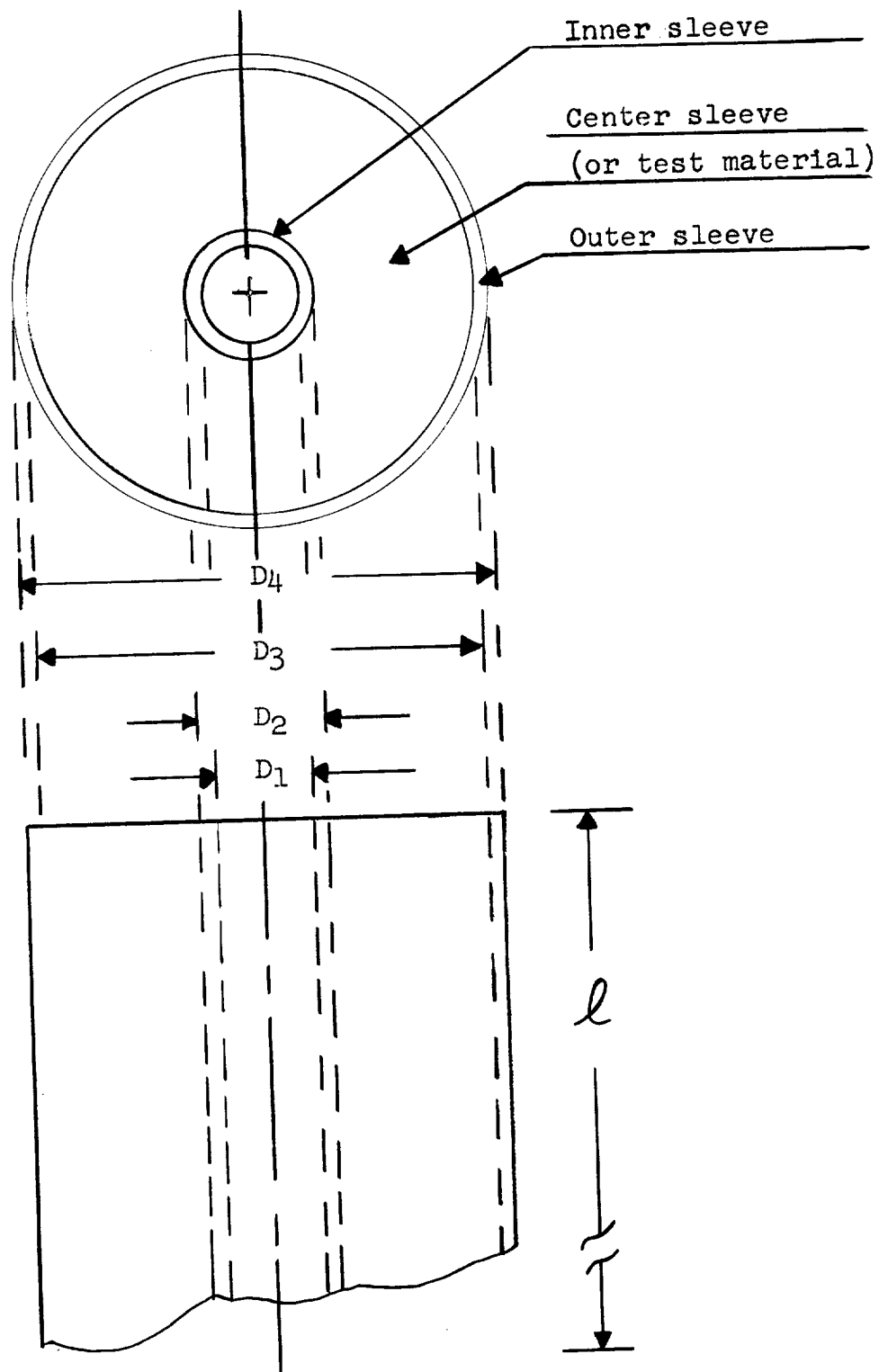


Figure A-2. Cylindrical Geometry Using Three Concentric Cylinders of Different Materials

Validity of the above expression for k_{m2} (which is k for the test material) depends upon the complete expenditure of the heat q , radially through the test specimen, and over the total length l .

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